Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-99

Gregory N. Katnik

Technical Memorandum - 2000 - 208565 March 2000

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DEBRIS/ICE/TPS ASSESSMENT AND INTEGRATED PHOTOGRAPHIC ANALYSIS OF SHUTTLE MISSION STS-99

11 February 2000

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FOREWORD

The Debris Team has developed and implemented measures to control damage from debris in the Shuttle operational environment and to make the control measures a part of routine launch flows. These measures include engineering surveillance during vehicle processing and closeout operations, facility and flight hardware inspections before and after launch, and photographic analysis of mission events.

Photographic analyses of mission imagery from launch, on-orbit, and landing provide significant data in verifying proper operation of systems and evaluating anomalies. In addition to the Kennedy Space Center Photo/Video Analysis, reports from Johnson Space Center and Marshall Space Flight Center are also included in this document to provide an integrated assessment of the mission.

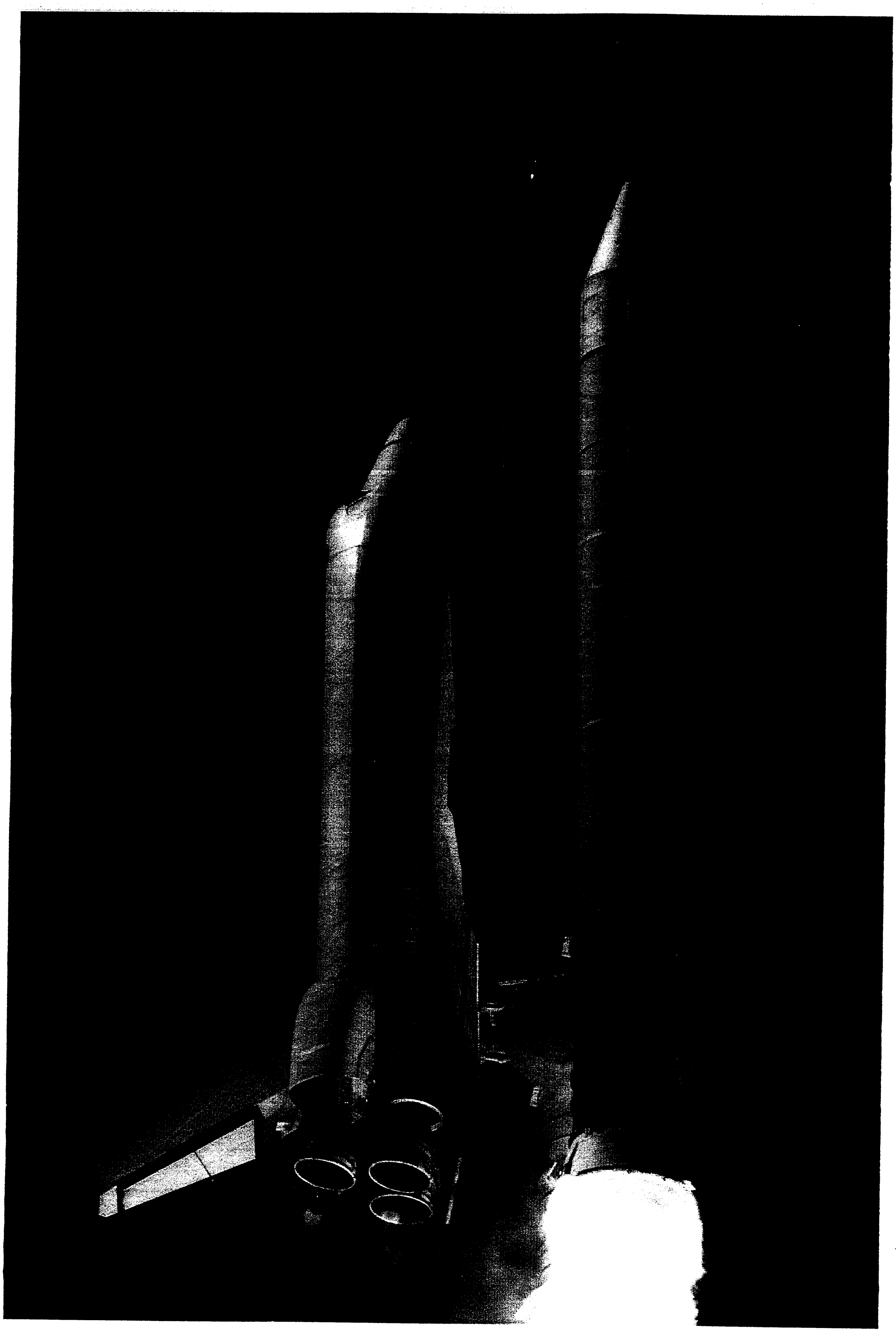


Photo 1: Launch of Shuttle Mission STS-99

1.0 SUMMARY OF SIGNIFICANT EVENTS

STS-99 consisted of OV-105 Endeavour (14^{th} flight), ET-92 (LWT configuration rather than SLWT), and BI-100 SRB's on MLP-3 and Pad 39A. Endeavour was launched at 042:17:43:40.005 UTC (12:43 p.m. local) on 11 February 2000. Landing was at 6:22 p.m. local/ eastern time on 22 February 2000.

Icicles on the GOX Vent Ducts

During the first launch attempt on 31 January 2000, the Final Inspection Team detected icicles on the exit planes of the GOX vent ducts. The largest icicles were estimated to be 8 inches long by 1 inch in diameter and approximately 40 pounds per cubic foot density. The weather conditions at the time were causing the icicles to grow in size as well as create new icicles. The Final Inspection Team made a determination the icicles would eventually break loose and the falling pieces of ice pose an impact threat to Orbiter left wing tiles. The Launch Team in the LCC was notified accordingly. Disposition of the IPR included a report from Launch Accessories that the GOX vent duct heated nitrogen purge was operating with specification at 180 degrees F.

While the team was on the pad, two icicles broke loose and fell generally southward. No impacts to the Orbiter wing were observed. Due to the hazards of strong wind, intermittent rain, and wet decking, it was not feasible for Final Inspection Team members to enter the GOX vent arm and remove the icicles using a net. Instead, a debris trajectory assessment was performed to evaluate the potential for impacts to the Orbiter.

The results showed no impacts to Orbiter left wing tiles for all cases of ice falling from the north GOX vent duct. For the south duct and 15-20 knots winds at 320 degrees, falling pieces were predicted to impact the upper surface mid-fuselage AFRSI at station Xo-1200. Based upon existing test data, minimal damage to the AFRSI would occur. For winds less than 10 knots at 340 degrees, falling ice would impact the Orbiter outboard wing RCC panels or lower surface TPS. The RCC test data showed the ice would have insufficient energy to cause RCC damage. For TPS damage, the predicted worst case was a crater approximately 0.5-inches deep and less than 2 inches long. This kind of damage would be within the experience database and acceptable for flight. For lower wind speeds and prevailing direction less then 320 degrees, the left SRB would shield the Orbiter wing.

The Ice Team performed surveillance of the GVA ducts and Orbiter left wing for falling ice and possible impacts throughout the remainder of the count. Icicles continued to break loose and fall during this time period. Although two possible impacts could not be confirmed, the absence of tile damage was verified.

Another critical event was the potential for the icicles to be shaken loose during GVA retraction. The Ice Team organized the necessary OTV surveillance, the analysis methods to size and assess damage sites, and the communications to inform the Launch Team of a Go/No-Go launch recommendation. However, the GOX vent ducts were eventually cleared of icicles by warming ambient temperatures and the prevailing winds. So the threat of tile damage was eliminated.

Note: after the launch attempt was scrubbed, disposition of the PR found the current configuration of ducts, heaters, insulation, and supporting hardware conformed to drawing specifications. The PR was then forwarded to Design Engineering for system enhancements to preclude a reoccurrence.

Cracks in the ET Longeron TPS

During the second launch attempt on 11 February 2000 prior to the on-pad inspection at T-3 hours, OTV surveillance detected two large frost spots and two possible cracks in the +Y longeron TPS closeout. The Final Inspection Team later discovered a total of four cracks. Since this condition was not an LCC Appendix F violation for acreage icing nor covered by the NSTS-08303 acceptance cases, further assessment was required and an IPR was taken.

In the forward inboard area of the longeron closeout was a 24-inch long by ¼-inch wide crack propagating diagonally aft and a 4-inch by 1/8-inch crack extending forward. In the aft outboard area, an 18-inch long by ¼-inch wide crack propagated diagonally forward and almost intersected the 24-inch crack. The fourth crack estimated to be 10 inches long by 1/8-inch wide was situated almost horizontally in the +Z direction. None of the cracks followed knit lines, exhibited offset, ice/frost, or venting.

The cracks most likely resulted from multiple cryogenic loading thermal/mechanical induced stresses in the TPS outer layer and localized defects in the thick BX-250 closeout foam. An assessment was performed that consisted of two parts addressing ET thermal/structural integrity for flight and possible debris threat to Orbiter lower surface tiles. With all the data taken, there was no evidence of debond and the condition appeared to consist of shallow surface cracks only.

The thick metal (mass) of the longeron is a heat sink. Coupled with the cryogenic temperatures on the interior side of the longeron, the structural temperature cannot increase significantly even if all the closeout foam was lost. This precluded thermal/stress concerns for ascent and re-entry. Due to the relatively small, localized area compared to the overall ET size, there was no propellant quality issues even if the longeron closeout TPS came off during launch.

Since the cracks exhibited no offset, foam adhesion to substrate and sidewall longeron ribs provide adequate strength, which would preclude large pieces of foam from coming loose. Only normal ablation would occur. Aero/thermal simulation data showed no foam loss when shallow cracks were present in the material. Therefore, there was no threat from TPS debris nor was there any concern about ice debris since frost, but no ice, had formed in association with the cracks.

Nevertheless, debris trajectory data was examined for possible impacts on Orbiter lower surface tiles. For three representative cases involving foam pieces of 12 x 12 x ¼-inch, 6 x 3 x 1 inch, and 3 x 3 x 3 inch sizes, there was no transport mechanism to impact the Orbiter from this location since the airflow is generally outboard from launch to Mach 4 (close to SRB separation). The database showed possible impacts above Mach 4 since the airflow has changed, but the dynamic pressure would be low and any debris particles would have energy too low to cause significant damage.

Based upon the integrated assessment, the condition was accepted for flight by MR.

2.0 PRE-LAUNCH

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted at 1400 on 28 January 2000. The following personnel participated in various team activities, assisted in the collection and evaluation of data, and contributed to reports contained in this document.

P. Weber	NASA - KSC	Chief, ET/SRB Mechanical Systems Branch
G. Katnik	NASA - KSC	Shuttle Ice/Debris Systems
R. Speece	NASA - KSC	Thermal Protection Systems
R. Stevens	NASA - KSC	SRB Mechanical Systems
J. Rivera	NASA - KSC	ET Mechanisms/Structures
W. Boyter	NASA - KSC	SRB Mechanical Systems
R. Page	NASA - KSC	SSP Integration
K. Revay	USA - SFOC	Supervisor, ET/SRB Mechanical Systems
J. Blue	USA - SFOC	ET Mechanical Systems
W. Richards	USA - SFOC	ET Mechanical Systems
M. Wollam	USA - SFOC	ET Mechanical Systems
T. Ford	USA - SFOC	ET Mechanical Systems
R. Seale	USA - SFOC	ET Mechanical Systems
R. Brewer	USA - SFOC	ET Mechanical Systems
R. Oyer	Boeing	Systems Integration
C. Hill	Boeing	Systems Integration
D. Leggett	Boeing	Systems Integration
J. McClymonds	Boeing	Shuttle Aerodynamics
M. Nowling	THIO - LSS	SRM Processing
S. Otto	LMMSS	ET Processing
J. Ramirez	LMMSS	ET Processing

2.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 30 January 2000. The walkdown of Pad 39A and MLP-3 included the flight elements OV-105 Endeavour (14^{th} flight), ET-92 (LWT configuration rather than SLWT), and BI-100 SRB's. There were no significant facility or SSV discrepancies and no items were entered in OMI S0007, Appendix K.

The weather forecast predicted a low of 45 degrees Fahrenheit at L-6 hours (0644 local) along with 62% RH and 5 knot winds at 330 degrees. By T-0, the temperature was expected to be 59 degrees F, 55% RH, and 10 knot winds at 330 degrees. Under these conditions, the computer program SURFICE calculated below-freezing temperatures on the LO2 tank barrel and upper LH2 tank. These temperatures were calculated to be greater than 32 degrees F at L-2 hours (1044 local). Frost, but no ice, was expected to form on the ET acreage during the early hours and be melted by the sun later in the day. Therefore, there would be no constraint to launch for icing.

3.0 SCRUB

3.1 FINAL INSPECTION – WEATHER SCRUB

A Final Inspection of the cryoloaded vehicle was performed on 31 January 2000 from 0720 to 0915 hours during the two-hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations relating to the flight hardware. One facility IPR (099V-1068) was taken for icicle formation on the GOX vent ducts and later upgraded to PR U-78-0001-00-001-0017.

At 12:25 GMT (0725 local), the Final Inspection Team on the FSS 255-foot level detected icicles on the exit planes of the GOX vent ducts: five on the south duct and four on the north duct. The largest icicles were estimated to be 8 inches long by 1 inch in diameter and approximately 40 pounds per cubic foot density. The weather conditions at the time – relatively cool temperatures, strong northwesterly 14-knot winds, and light rain/mist – were causing the icicles to grow in size as well as create new icicles. These conditions were expected to continue until 1200 hours local. The Final Inspection Team made a determination the icicles would eventually break loose and the falling pieces of ice pose an impact threat to Orbiter left wing tiles. The Launch Team in the LCC was notified accordingly. Disposition of the IPR included a report from Launch Accessories that the GOX vent duct heated nitrogen purge was operating with specification at 180 degrees F.

While the team was on the pad, two icicles broke loose by 14:32 GMT and fell generally southward. No impacts to the Orbiter wing were observed. Due to the hazards of strong wind, intermittent rain, and wet decking, it was not feasible for Final Inspection Team members to enter the GOX vent arm and remove the icicles using a net. Instead, a debris trajectory assessment was performed to evaluate the potential for impacts to the Orbiter.

The results showed no impacts to Orbiter left wing tiles for all cases of ice falling from the north GOX vent duct. For the south duct and 15-20 knots winds at 320 degrees, falling pieces were predicted to impact the upper surface mid-fuselage AFRSI at station Xo-1200. Based upon existing test data, minimal damage to the AFRSI would occur. For winds less than 10 knots at 340 degrees, falling ice would impact the Orbiter outboard wing RCC panels or lower surface TPS. The RCC test data showed the ice would have insufficient energy to cause RCC damage. For TPS damage, the predicted worst case was a crater approximately 0.5-inches deep and less than 2 inches long. This kind of damage would be within the experience database and acceptable for flight. For lower wind speeds and prevailing direction less then 320 degrees, the left SRB would shield the Orbiter wing.

The Ice Team performed surveillance of the GVA ducts and Orbiter left wing for falling ice and possible impacts throughout the remainder of the count. Icicles continued to break loose and fall during this time period. Although two possible impacts could not be confirmed, the absence of tile damage was verified.

Another critical event was the potential for the icicles to be shaken loose during GVA retraction. The Ice Team organized the necessary OTV surveillance, the analysis methods to size and assess damage sites, and the communications to inform the Launch Team of a Go/No-Go launch recommendation. However, the GOX vent ducts were eventually cleared of icicles by warming ambient temperatures and the prevailing winds. So the threat of tile damage was eliminated.

Note: after the launch attempt was scrubbed, disposition of the PR found the current configuration of ducts, heaters, insulation, and supporting hardware conformed to drawing specifications. The PR was then forwarded to Design Engineering for system enhancements to preclude a reoccurrence.

Technically considered a "winter" launch, there were no acreage icing concerns due to warmer ambient temperatures and stronger winds later in the day. Although wet from rain, the ET LO2 tank acreage temperatures averaged 43-47 degrees F at the time of the inspection. The 12x12-inch sanded area of the LO2 tank +Z side was 43.5 degrees F. The average surface temperatures on the LH2 tank ranged from 40 to 47 degrees F. There were also no protuberance icing conditions outside of the established database. Frost had formed on the –Y bipod ramp bond line. The –Y vertical strut exhibited a stress relief crack approximately 10 inches long by 3/8-inches wide, which was acceptable for flight per NSTS-08303.

There were no tile or RCC panel anomalies on the Orbiter. All RCS thrust paper covers were intact but somewhat wet due to recent rain. Typical amounts of ice and frost had formed on the SSME nozzle to heat shield interface.

Launch was scrubbed at the end of the window due to numerous weather violations and a faulty Main Events Controller (E-MEC).

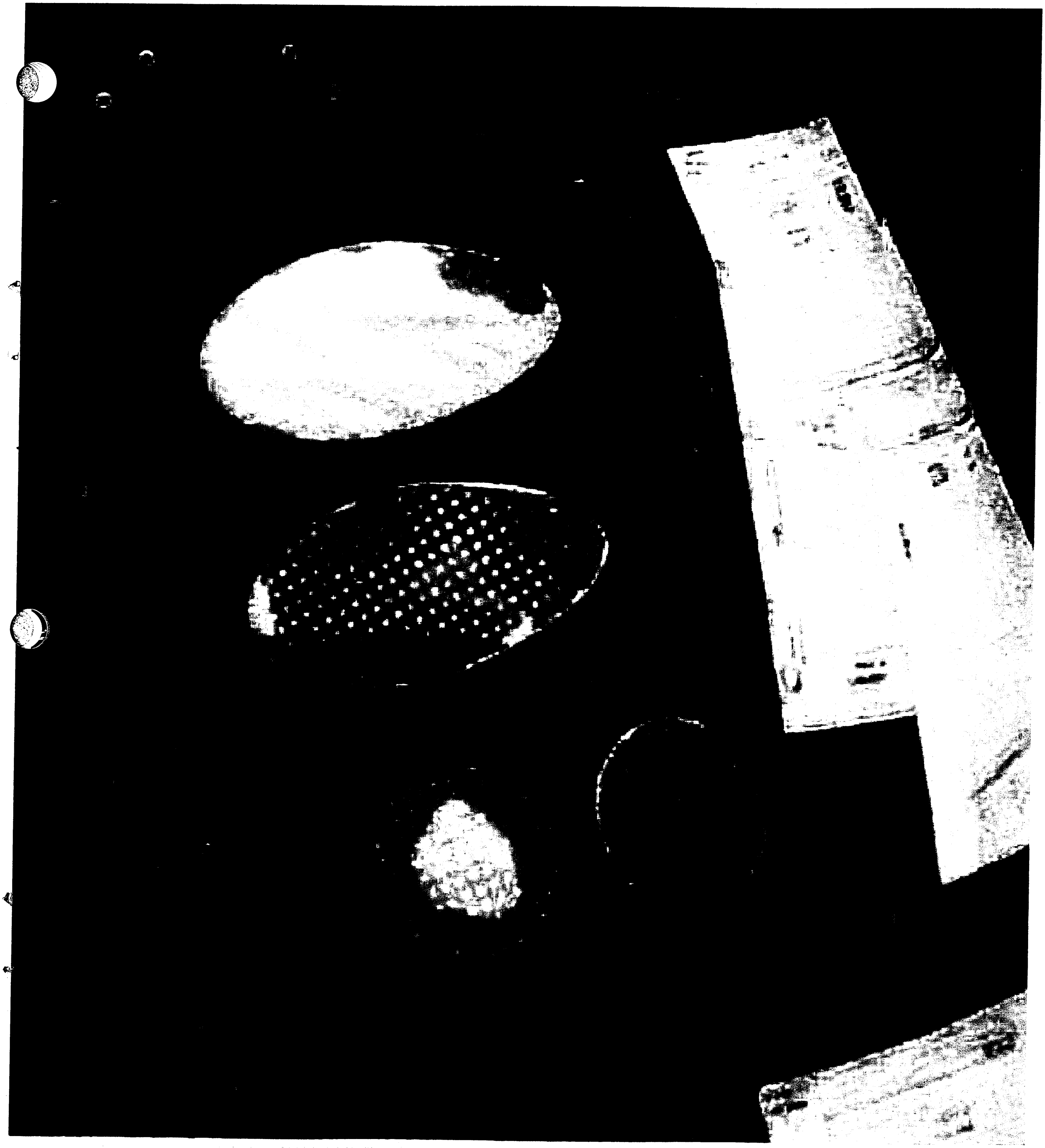


Photo 2: Discolored FRCS Thruster Covers

All RCS thrust paper covers were intact but somewhat wet due to recent rain

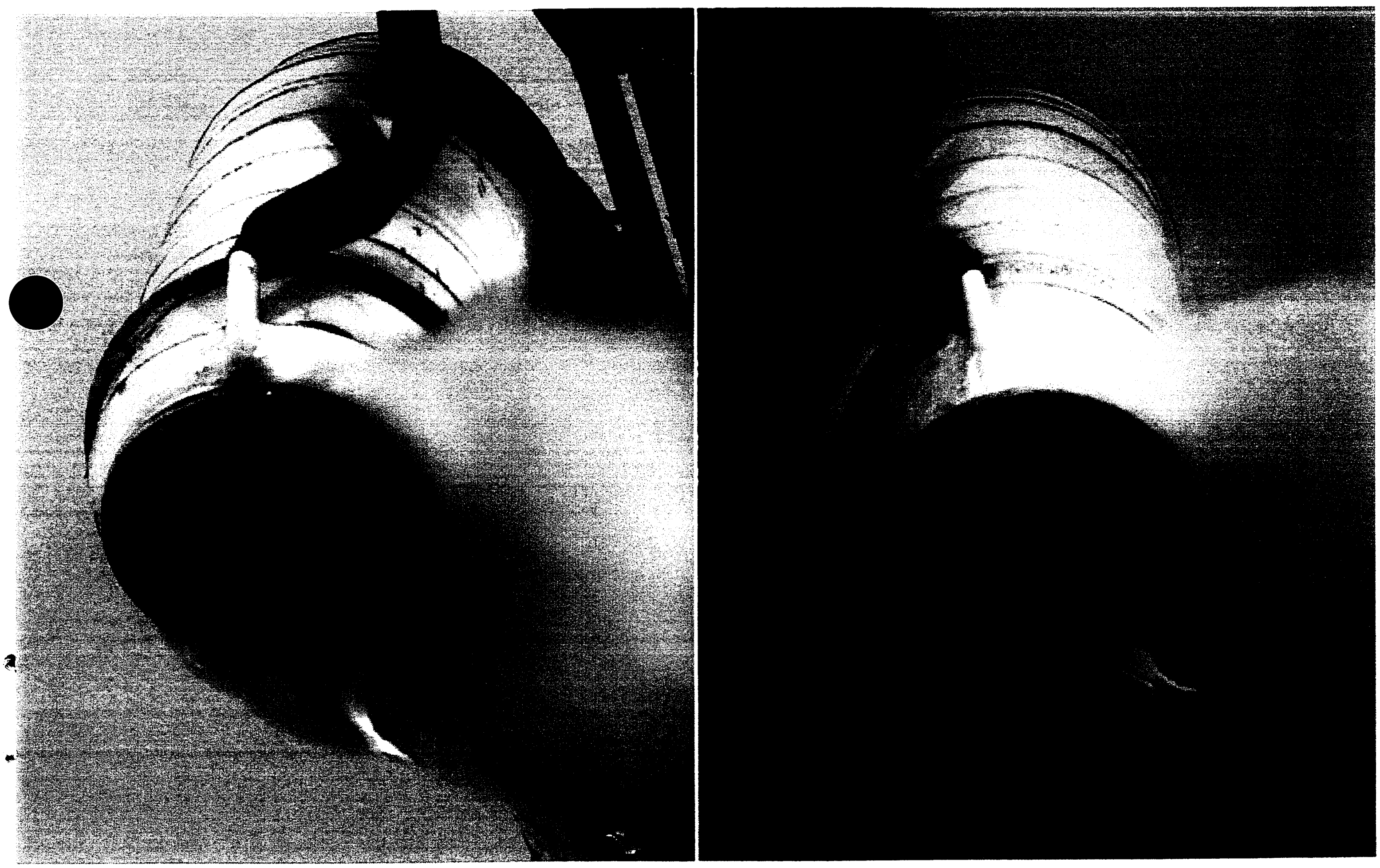


Photo 3: Icicles of GOX Vent Ducts

The Final Inspection Team on the FSS 255-foot level detected icicles on the exit planes of the GOX vent ducts: five on the south duct and four on the north duct. The largest icicles were estimated to be 8 inches long by 1 inch in diameter and approximately 40 pounds per cubic foot density.

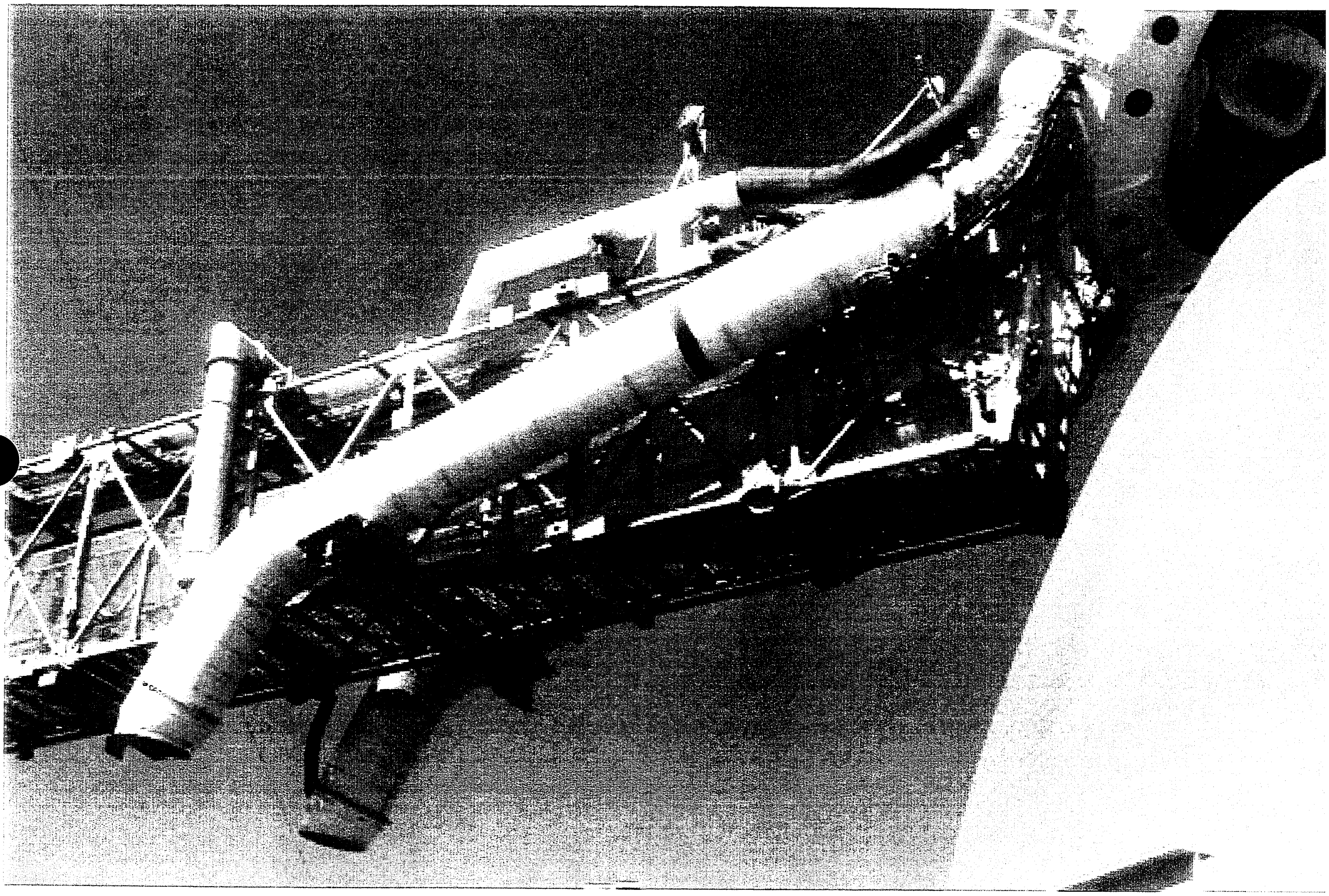


Photo 4: Side View of GOX Vent Ducts

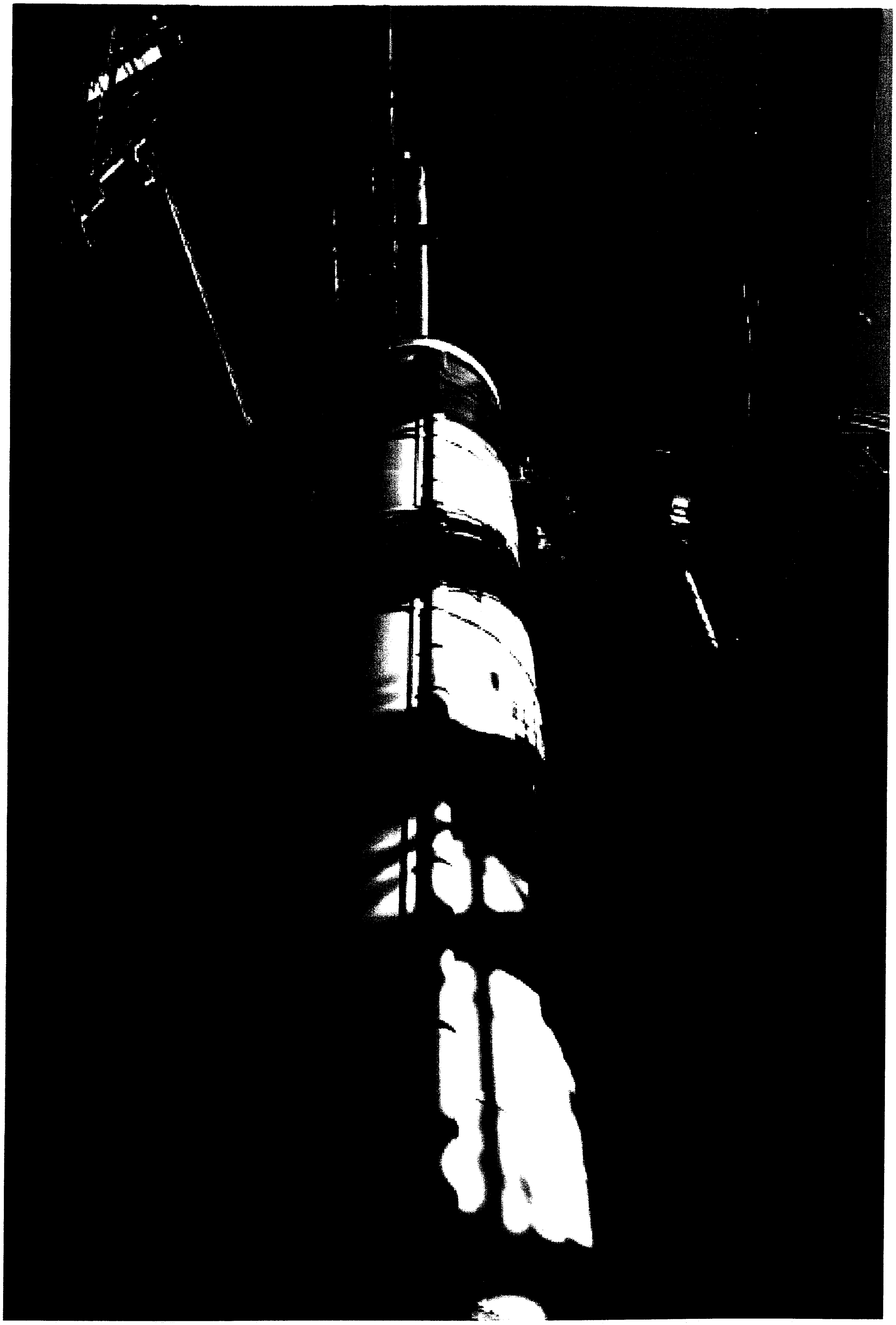


Photo 5: Proximity to Flight Hardware

View showing ends of GOX vent ducts in relation to left SRB and Orbiter left wing lower surface

Photo 6: Orbiter TPS Susceptible to Falling Ice Impacts

3.2 POST DRAIN INSPECTION

The post drain inspection of STS-99, MLP-3, and Pad A FSS was conducted on 31 January 2000 from 1910 to 2005 hours under dark conditions and steady rain. Nevertheless, visibility was adequate for the inspection.

No MLP deck or facility anomalies were detected.

Likewise, no anomalies were observed on the SRB's.

Orbiter tiles, RCC panels, and SSME's were in nominal configuration. RCS thruster paper covers were intact, though many were wet in varying degrees due to the rain. However, the wetted areas were not soaked to the point of water intrusion to the thruster throats. Two of the forward RCS thruster papers on the –Y side were also discolored to a purple hue with no visible fluid level.

The External Tank was in excellent condition. No topcoat was missing from the nose cone area under the GOX vent seal footprint. Bipod jack pad standoff closeouts were in nominal condition. All PDL repairs were intact with none protruding. No crushed foam or debris was detected in the LO2 feedline support brackets. The stress relief crack in the –Y vertical strut forward facing TPS was still present.

The warm rain had removed most of the ice/frost accumulations. The only ice remaining was located in the LO2 feedline bellows, -Y aft fairing-to-ET/SRB cable tray interface, and on the ET/ORB umbilical purge vents.

In summary, no IPR conditions and no flight hardware concerns were detected during the post drain inspection. There were no constraints for the next cryoload.

4.0 LAUNCH

4.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

Due to the long interval of time between launch attempts, a second pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 10 February 2000. The detailed walkdown of Pad 39A and MLP-3 included the flight elements OV-105 Endeavour (14th flight), ET-92 (LWT configuration rather than SLWT), and BI-100 SRB's. There were no significant SSV discrepancies. However, four loose plates on the MLP zero level, several broken tether chains on TSM electrical connectors, loose bolts on the east MLP access tower, missing cotter pins from a platform on the same access tower, and debris in the rain gutters, were entered as line items in OMI S0007, Appendix K. All of these items were verified as being resolved during the T-8 hour inspection.

The weather forecast predicted a low of 54 degrees F at L-6 hours (0630 local) along with 90% RH and 5 knot winds at 210 degrees. By T-0, the temperature was expected to be 75 degrees F, 45% RH, and 14-knot winds at 220 degrees. Under these conditions, the computer program SURFICE calculated ET TPS surface temperatures below 32 degrees F during the first few hours of cryoload, but warming to temperatures well above freezing by T-0. Therefore, there would be no constraint to launch due to acreage icing.

4.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 11 February 2000 from 0700 to 0845 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC) or OMRS criteria violations. There were no acreage icing concerns. There were also no protuberance icing conditions outside of the established database. However, an IPR was taken for multiple surface cracks in the +Y longeron closeout TPS.

A portable Shuttle Thermal Imager (STI) infrared scanning radiometer was utilized to obtain vehicle surface temperature measurements for an overall thermal assessment of the vehicle, particularly those areas not visible from remote fixed scanners, and to scan for unusual temperature gradients.

4.2.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. The RCS thruster paper covers were intact but seven covers (F2R, F4R, F3D, F1L, L2D, R4D, R4U) were tinted light green in color indicating very slight leaks. Ice/frost had formed on the SSME #1 and #2 heat shield-to-nozzle interfaces. The SSME #3 heat shield was dry.

4.2.2 SOLID ROCKET BOOSTERS

SRB case temperatures measured by the STI radiometers were close to ambient temperatures. All measured temperatures were above the 34 degrees F minimum requirement. The predicted Propellant Mean Bulk Temperature supplied by THIO was 73 degrees F, which was within the required range of 44-86 degrees F.

4.2.3 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run as a comparison to infrared scanner point measurements. The program predicted below freezing temperatures and frost at the start of cryoload. However, warming ambient conditions soon melted the frost. There were no ice formations on the ET acreage TPS.

Prior to the on-pad inspection at T-3 hours, OTV surveillance detected two large frost spots and two possible cracks in the +Y longeron TPS closeout. The Final Inspection Team later discovered a total of four cracks. Since this condition was not an LCC Appendix F violation for acreage icing nor covered by the NSTS-08303 acceptance cases, further assessment was required and IPR 099V-0193 was taken.

In the forward inboard area of the longeron closeout was a 24-inch long by ¼-inch wide crack propagating diagonally aft and a 4-inch by 1/8-inch crack extending forward. In the aft outboard area, an 18-inch long by ¼-inch wide crack propagated diagonally forward and almost intersected the 24-inch crack. The fourth crack estimated to be 10 inches long by 1/8-inch wide was situated almost horizontally in the +Z direction. None of the cracks followed knit lines, exhibited offset, ice/frost, or venting. Although the cracks measured 23 degrees F when imaged by the infrared radiometer, the surrounding TPS was 44 degrees. In fact, when the foam expanded in the warm sunlight, there was some closure.

The cracks most likely resulted from multiple cryogenic loading thermal/mechanical induced stresses in the TPS outer layer and localized defects in the thick BX-250 closeout foam. An assessment was performed that consisted of two parts addressing ET thermal/structural integrity for flight and possible debris threat to Orbiter lower surface tiles. With all the data taken, there was no evidence of debond and the condition appeared to consist of shallow surface cracks only.

The thick metal (mass) of the longeron is a heat sink. Coupled with the cryogenic temperatures on the interior side of the longeron, the structural temperature cannot increase significantly even if all the closeout foam was lost. This precluded thermal/stress concerns for ascent and re-entry. Due to the relatively small, localized area compared to the overall ET size, there was no propellant quality issues even if the longeron closeout TPS came off during launch.

Since the cracks exhibited no offset, foam adhesion to substrate and sidewall longeron ribs provide adequate strength, which would preclude large pieces of foam from coming loose. Only normal ablation would occur. Aero/thermal simulation data showed no foam loss when shallow cracks were present in the material. Therefore, there was no threat from TPS debris nor was there any concern about ice debris since frost, but no ice, had formed in association with the cracks.

Nevertheless, debris trajectory data was examined for possible impacts on Orbiter lower surface tiles. For three representative cases involving foam pieces of 12 x 12 x ¼-inch, 6 x 3 x 1 inch, and 3 x 3 x 3 inch sizes, there was no transport mechanism to impact the Orbiter from this location since the airflow is generally outboard from launch to Mach 4 (close to SRB separation). The database showed possible impacts above Mach 4 since the airflow has changed, but the dynamic pressure would be low and any debris particles would have energy too low to cause significant damage.

Considering the possibility the foam really was debonded at the substrate and ice was present, ice debris would most likely come loose during maximum dynamic pressure, vibration, and/or heating. However, recalling that only at speeds above Mach 4 is a transport mechanism present to carry debris to lower surface tiles, the dynamic pressure and vibration peak at approximately 57 seconds – well before Mach 4. Ambient pressure falls to very low levels prior to Mach 4, so vacuum driven expulsion was unlikely. Vaporization of cryo-pumped air would occur well after Mach 4 and would be no issue. Even if all material lost was ice with a 57 lbs./cu. ft. density, tile damage would still fall within the experience database and be acceptable for flight.

In conclusion, the condition was accepted for flight by MR.

During this second cryoload, the Final Inspection Team observed generally dry TPS on the LO2 tank acreage with some patches of ice in the –Y-Z and –Y+Z quadrants, but no ice formations. Surface temperatures ranged from 27 to 32 degrees Fahrenheit in the frosted areas and 42-46 degrees in the sunlit areas.

No significant anomalies were detected in the intertank TPS though ice/frost had formed along the outboard –Y bipod housing closeout bondline. Ice and frost accumulations on the GUCP were typical. There were no stringer valley TPS cracks.

Much of the LH2 tank acreage, particularly the –Z side, was covered by frost. Some patches of frost had also formed in the +Y+Z quadrant, but quickly melted. Surface temperatures ranged from 32 degrees Fahrenheit range in the frosted areas to 43 degrees in the sunlit areas.

Somewhat greater than usual amounts of ice/frost had accumulated in the LO2 feedline bellows and support brackets as expected given the ambient weather conditions. But these accumulations were still acceptable for flight per NSTS-08303. Also as expected for a second cryoload, there were numerous small frost spots on various closeout bondlines including one place on the +Y bipod jack pad standoff outboard aft closeout.

A 12-inch long by 3/8-inch wide stress relief crack had formed on the -Y vertical strut forward facing TPS. There was no ice/frost present and no offset. The condition was acceptable for launch per the NSTS-08303 criteria.

There were no TPS anomalies on the LO2 ET/ORB umbilical. Ice/frost accumulations were present on the aft and inboard sides. Ice/frost fingers on the separation bolt pyrotechnic canister purge vents were typical.

Ice/frost had formed in the LH2 feedline bellows and on the straight section of the feedline. Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. Likewise, a typical amount of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier outboard side, forward, and aft surfaces. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

4.2.4 FACILITY

All SRB sound suppression water troughs were filled and properly configured for launch. No leaks were observed on the GUCP or the LO2 and LH2 Orbiter T-0 umbilicals. Two very small, ¼-inch long icicles had formed on the north GOX vent duct and were no threat to Orbiter tiles.

4.3 T-3 HOURS TO LAUNCH

After completion of the Final Inspection on the pad, surveillance continued from the Launch Control Center. Twenty-two remote-controlled television cameras and two infrared radiometers were utilized to perform scans of the vehicle. No ice or frost on the acreage TPS was detected. Protuberance icing previously assessed did not increase. At T-2:30, the GOX vent seals were deflated and the GOX vent hood lifted. An area of topcoat estimated to be 10 inches long by 3 inches wide adhered to the northeast seal. Although frost covered some of the ET nose cone louvers - an expected condition - no ice was detected. When the heated purge was removed by retraction of the GOX vent hood, frost continued to form on the louvers until liftoff. At the time of launch, there were no ice accumulations in the "no ice zone".

STS-99 was launched at 042:17:43:40.005 UTC (12:43 p.m. local) on 11 February 2000.

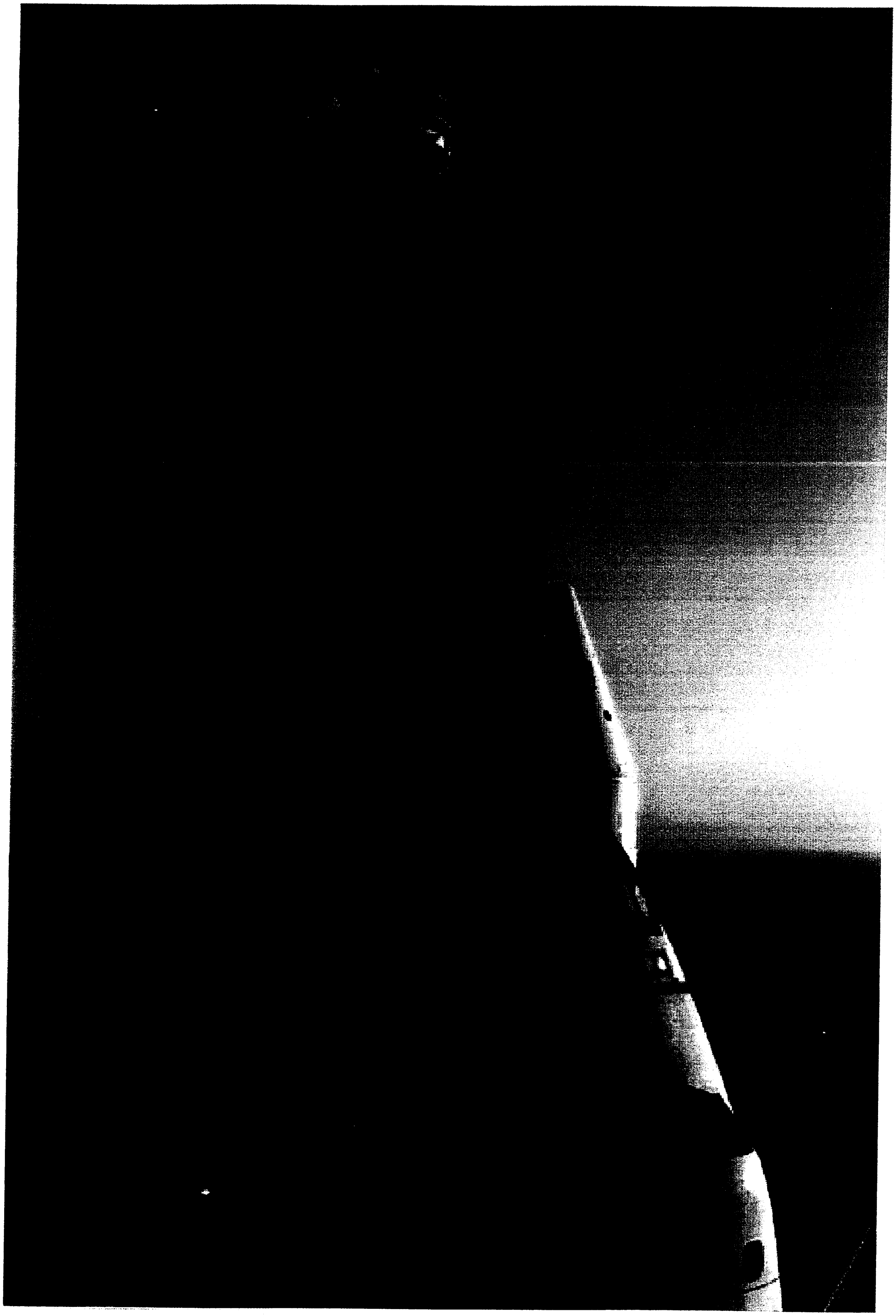


Photo 7: ET LO2 Tank and Intertank

During this second cryoload, the Final Inspection Team observed generally dry TPS on the LO2 tank acreage with some patches of ice in the –Y-Z and –Y+Z quadrants, but no ice formations. Surface temperatures ranged from 27 to 32 degrees Fahrenheit in the frosted areas and 42-46 degrees in the sunlit areas.

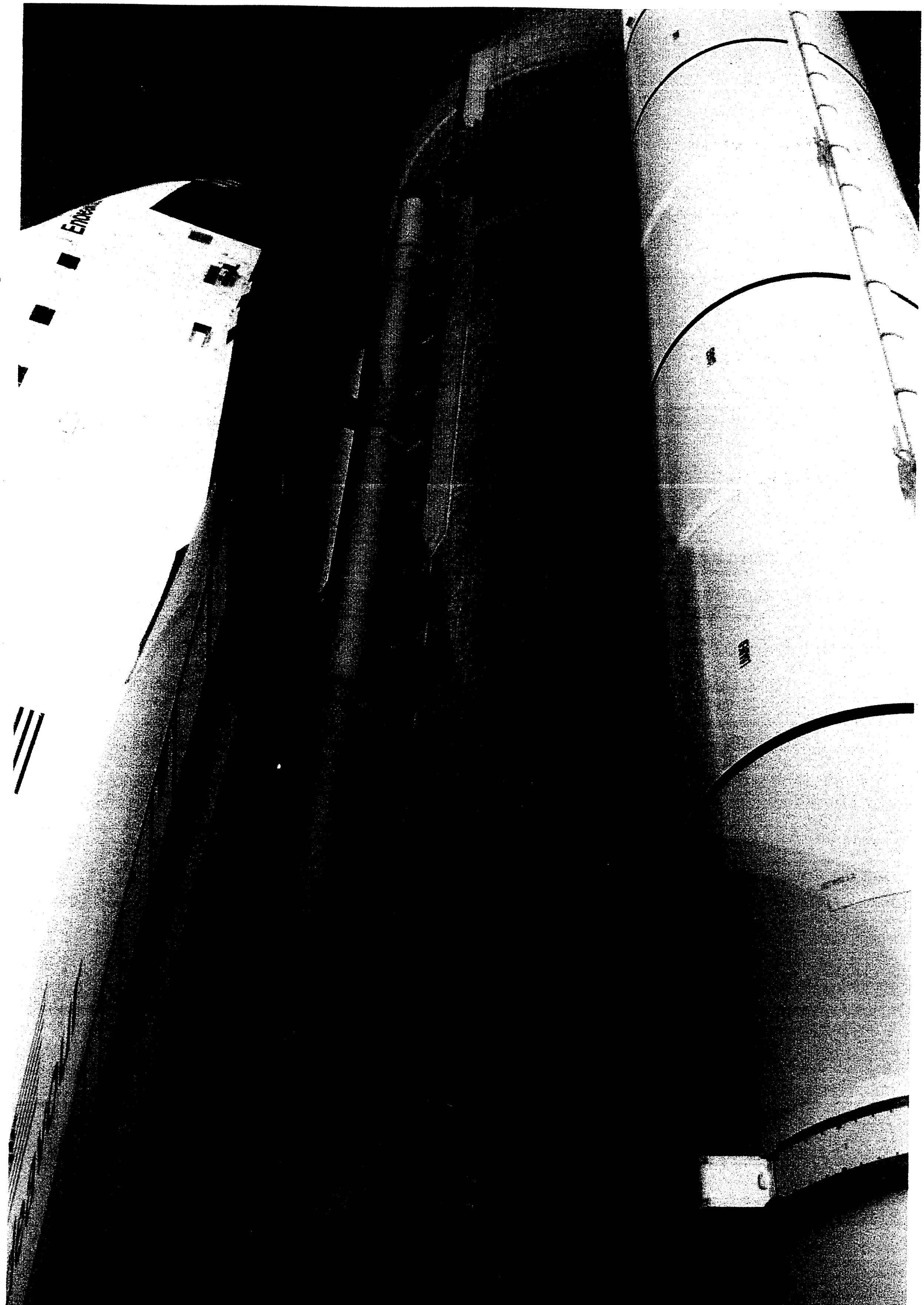


Photo 8: Frost on LH2 Tank

Some patches of frost had formed in the +Y+Z quadrant, but quickly melted. Surface temperatures ranged from 32 degrees Fahrenheit range in the frosted areas to 43 degrees in the sunlit areas. Note frost on LO2 tank barrel section.

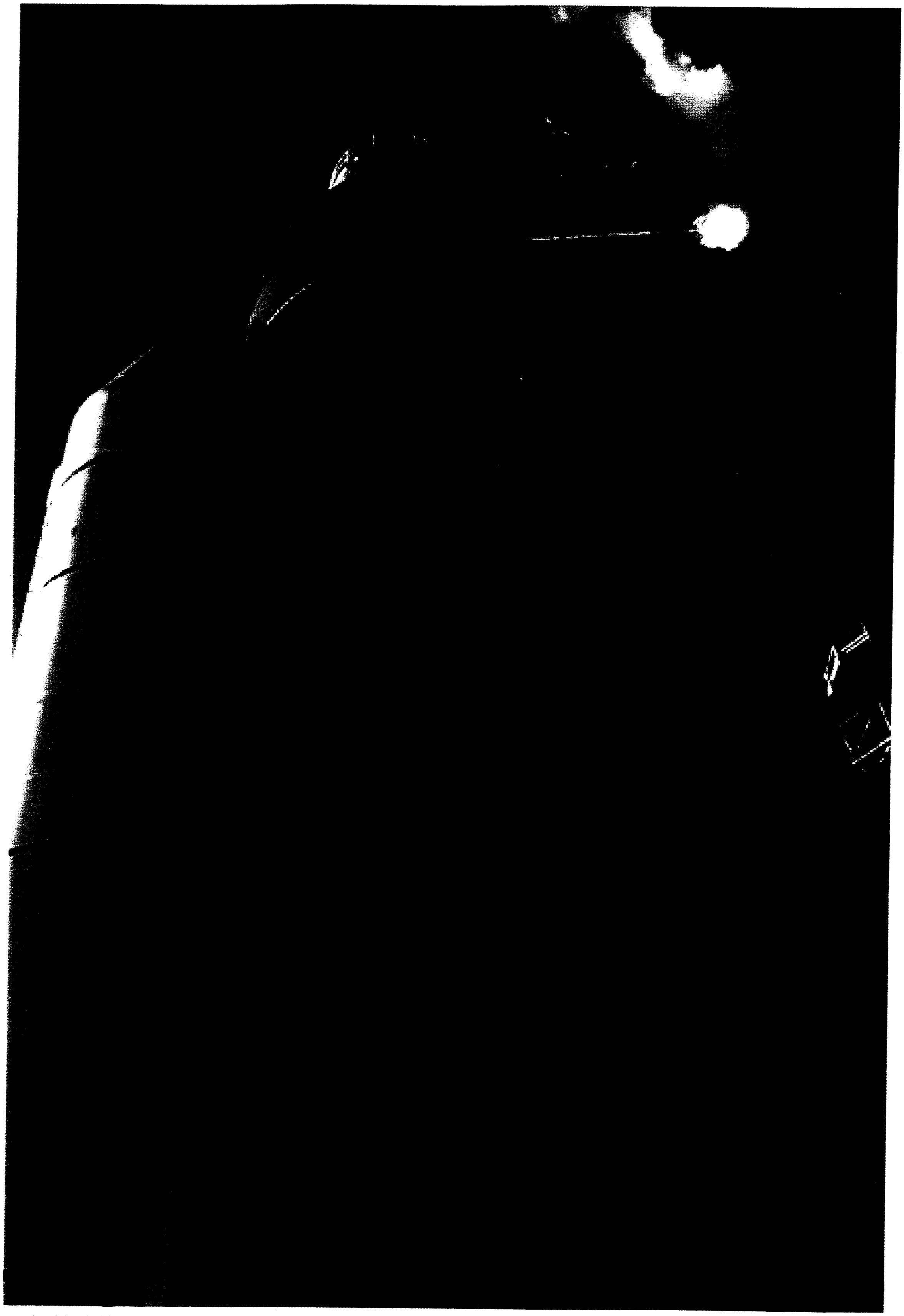


Photo 9: Frost on –Z Side

Much of the LH2 tank acreage, particularly the –Z side, was covered by frost. Surface temperatures ranged from 32 degrees Fahrenheit range in the frosted areas to 43 degrees in the sunlit areas.

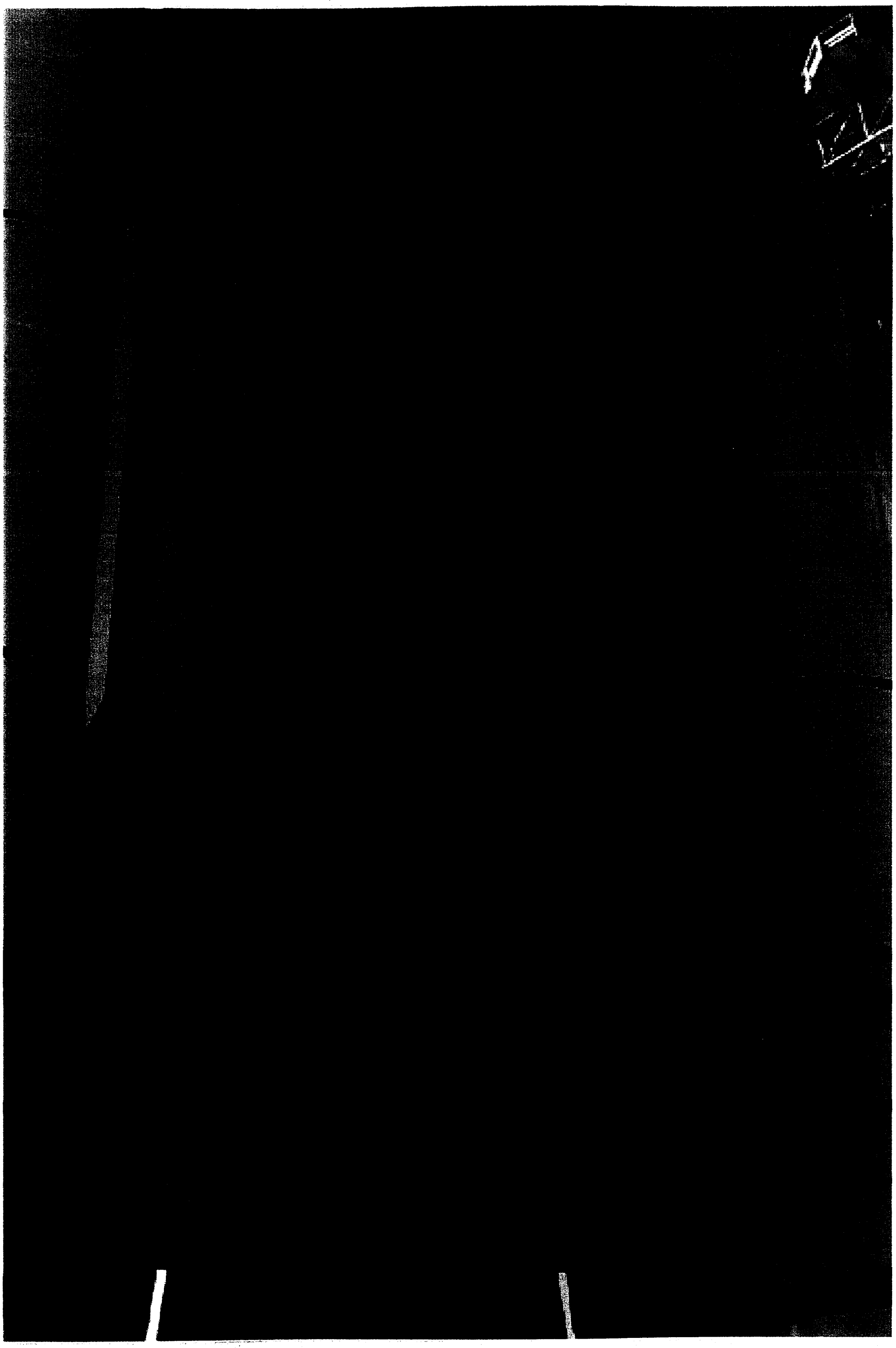


Photo 10: Frost on –Z Side

Photo 11: Cracks in Longeron TPS

Prior to the on-pad inspection at T-3 hours, OTV surveillance detected two large frost spots and two possible cracks in the +Y longeron TPS closeout. The Final Inspection Team later discovered a total of four cracks. Since this condition was not an LCC Appendix F violation for acreage icing nor covered by the NSTS-08303 acceptance cases, further assessment was required.

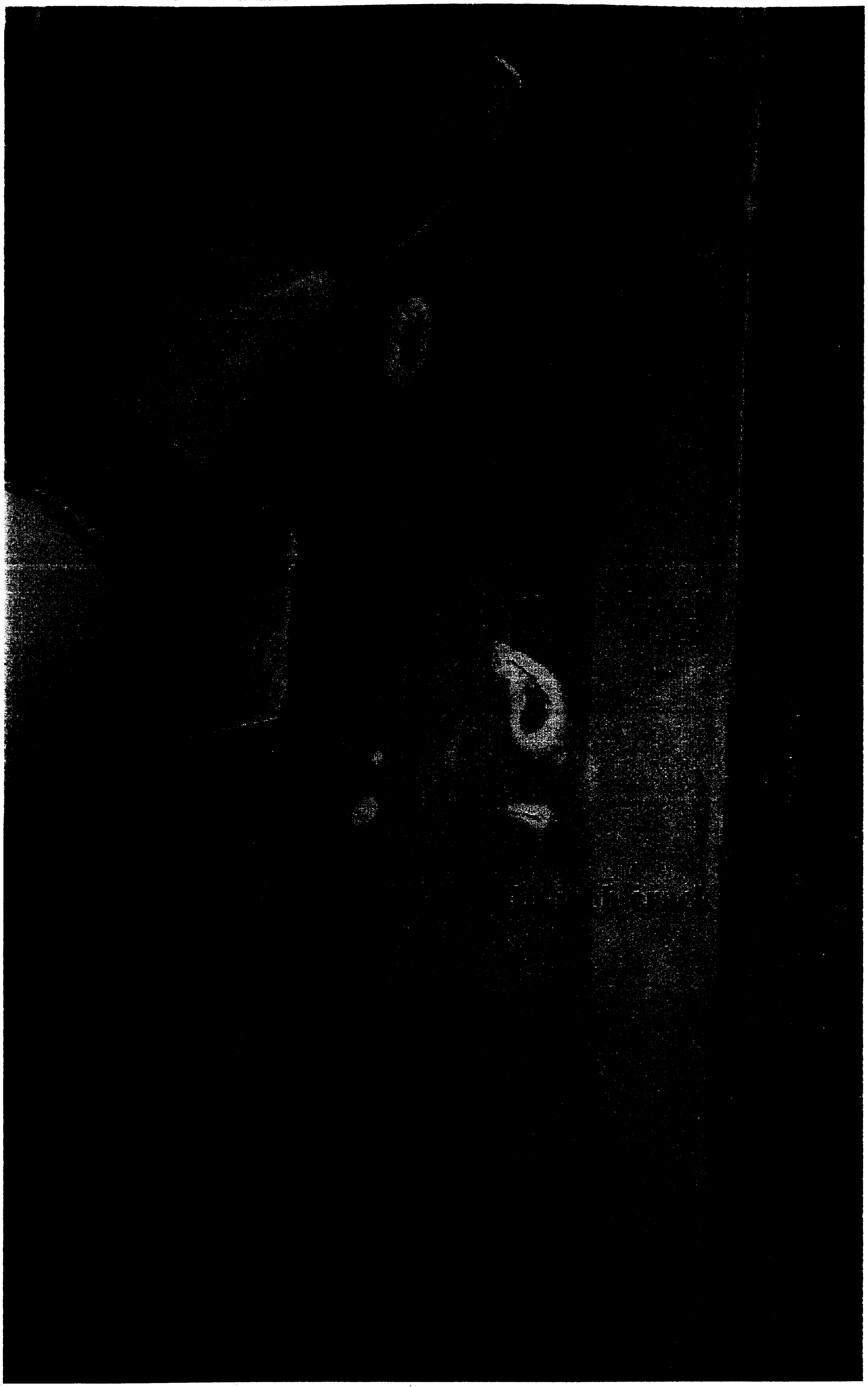


Photo 12: Enhanced Image of TPS Cracks

In the forward inboard area of the longeron closeout was a 24-inch long by ¼-inch wide crack propagating diagonally aft and a 4-inch by 1/8-inch crack extending forward. In the aft outboard area, an 18-inch long by ¼-inch wide crack propagated diagonally forward and almost intersected the 24-inch crack. The fourth crack estimated to be 10 inches long by 1/8-inch wide was situated almost horizontally in the +Z direction. None of the cracks followed knit lines, exhibited offset, ice/frost, or venting.

Photo 13: Overall View of SSME's

5.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of the MLP, Pad A FSS and RSS was conducted on 11 February 2000 from Launch + 3 to 5 hours. No flight hardware was found.

A stud hang-up was not expected on this launch. Boeing-Downey reported an Orbiter liftoff lateral acceleration of 0.11g's which is below the threshold (0.14g's) for stud hang-ups. Erosion was typical for the south posts. North holddown post blast covers and T-0 umbilical exhibited typical exhaust plume damage. Both SRB aft skirt GN2 purge lines were intact, though the protective tape had eroded away.

The LO2 Tail Service Mast (TSM) appeared undamaged and the bonnet was closed properly. The LH2 TSM inboard closeout plates appeared displaced. The large plate on the east side appeared to be shifted down about 1-2 inches. A smaller diagonally oriented plate appeared to be broken loose on the lower end and rotated slightly. The LH2 bonnet was properly closed. The MLP deck was in good shape with no significant debris items.

The GH2 vent line latched in the eighth of eight teeth of the latching mechanism. The GUCP 7-inch QD sealing surface exhibited no damage. All observations indicated a nominal retraction and latchback.

No damage was detected on the Orbiter Access Arm (OAA).

The GOX vent arm, hood, ducts and structure appeared to be in good shape with no indications of plume damage. Topcoat adhered to a 12 inch long by 1-1/2 inch wide area on the northeast GOX vent seal. This had occurred during GOX vent hood retraction. Several small spots of topcoat adhered to both seals.

Debris findings on the FSS included loose cable tray covers and brackets, a 3-1/2 foot long by 5-inch wide flow diverter from the underside of the 215-ft level OAA egress path on the 195-ft level near the elevator door, a large lump of putty (~ 1 lb.) on the 195-ft level, and a broken fire hose reel cover displaced from the 95-ft level. The 135 and 155-ft levels each had rusted purge panels, which produced large rust scale debris.

The brake covers for the RSS drive motor trucks were blown open.

No damage was noted in the flame trenches. Two flame-cut steel disks, approximately 4 inches in diameter by 1 inch thick, were found in the south trench. A similar 8-inch diameter disk was found embedded in the north perimeter fence. The three disks did not pose a threat to flight hardware since no objects of this size were observed near the vehicle in the launch films. Debris emanating from the flame trenches, such as brick and mortar, are commonly transported by the exhaust plumes to outlying acreage areas of the pad without incident to the vehicle.

No flight debris was found on the Pad acreage. Overall, damage to the pad appeared to be minimal.

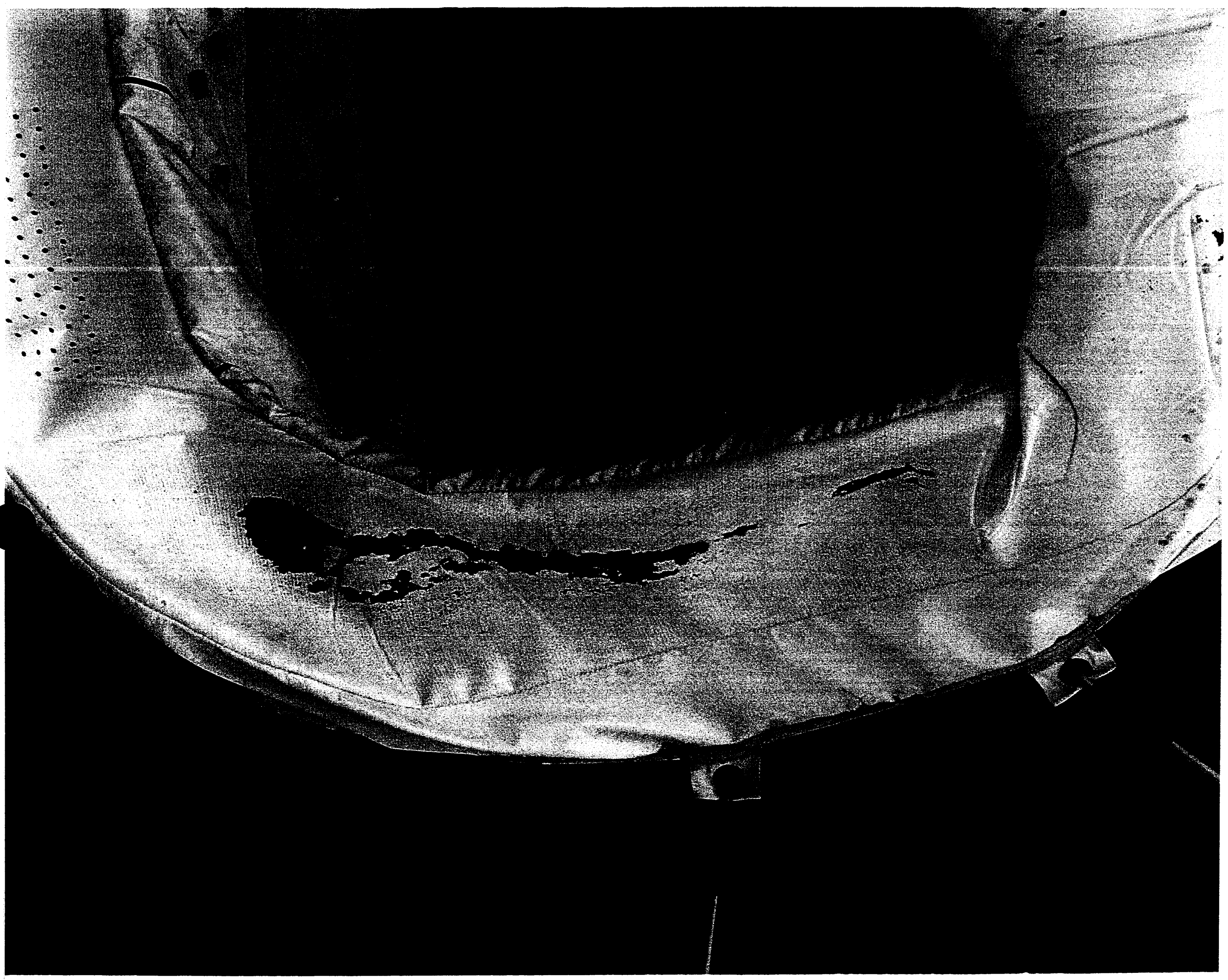


Photo 14: ET Topcoat of GOX Vent Seal

Topcoat adhered to a 12 inch long by 1-1/2 inch wide area on the northeast GOX vent seal. This had occurred during GOX vent hood retraction.

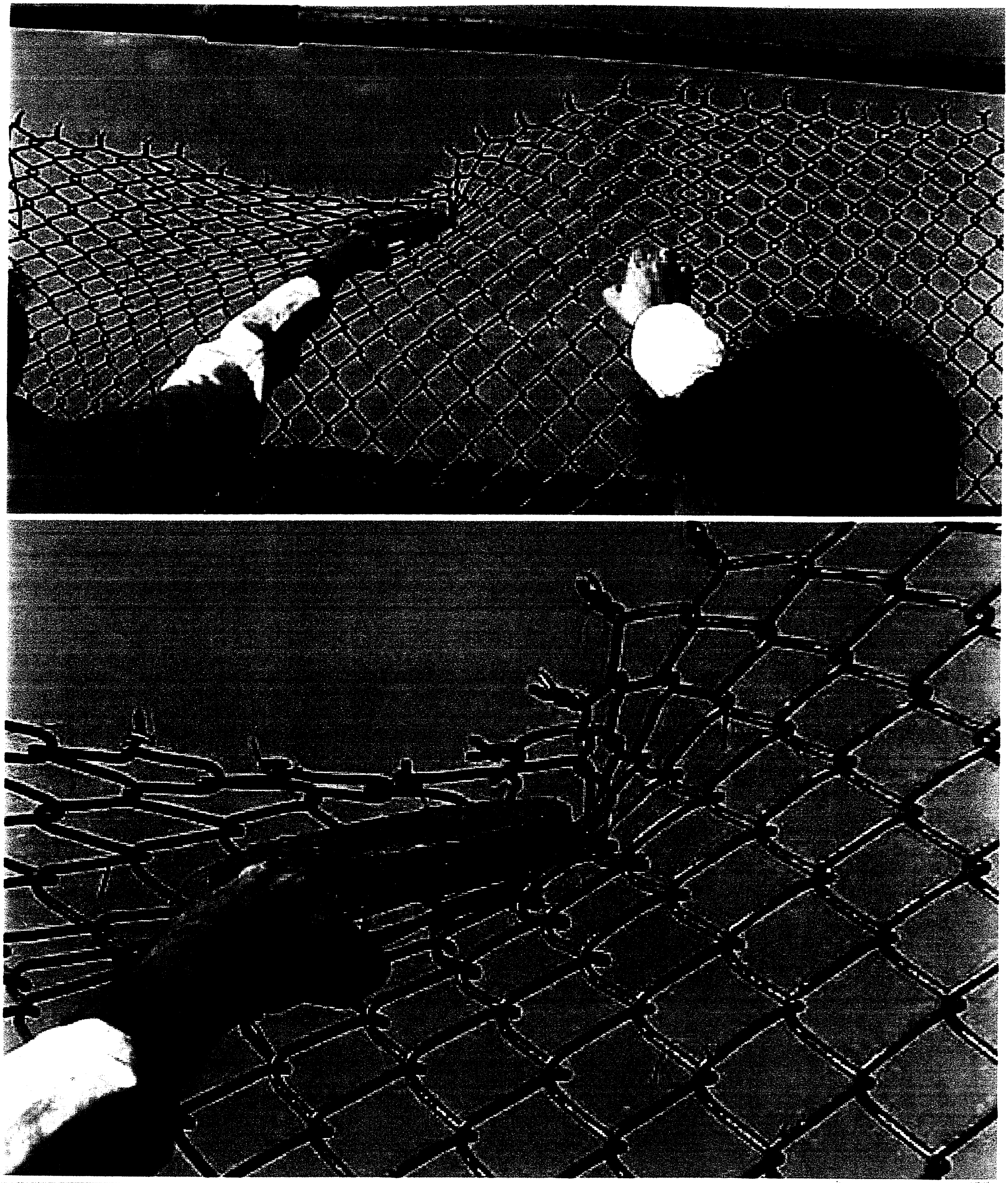


Photo 15: Metal Disk Embedded in Perimeter Fence

Two flame-cut steel disks, approximately 4 inches in diameter by 1 inch thick, were found in the south trench. A similar 8-inch diameter disk was found embedded in the north perimeter fence. The three disks did not pose a threat to flight hardware since no objects of this size were observed near the vehicle in the launch films. Debris emanating from the flame trenches, such as brick and mortar, are commonly transported by the exhaust plumes to outlying acreage areas of the pad without incident to the vehicle.

6.0 FILM REVIEW

Anomalies observed in the Film Review were reported to the Mission Management Team, Shuttle managers, and vehicle systems engineers. No IPR's or IFA's were generated as a result of the film review.

6.1.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 84 films and videos, which included twenty-eight 16mm films, eighteen 35mm films, and thirty-eight videos, were reviewed starting on launch day.

Frost, but no ice, formed on the ET louvers after GOX vent seal retraction. An area of topcoat, estimated to be 10 inches long by 3 inches wide, had adhered to the northeast louver (OTV 060). Very small areas of missing topcoat were visible near the southwest ET louver (E-40).

SSME ignition appeared normal with Mach diamonds appearing in a proper 3-2-1 sequence. Numerous orange streaks occurred along the edge of the SSME #1 exhaust plume during start-up through early liftoff (E-2, -3, -19, -20, -52, -77; OTV 051, 070, 071).

Free burning hydrogen rose to the orbiter base heat shield area and drifted under the body flap due to the southerly winds during SSME ignition (OTV 063, 070, 071, TV-7).

A rectangular object, approximately 6 inches long by 2 inches wide fell between SSME #2/#3 and the body flap at 17:43:37.836 UTC. The object, which may be a tile gap filler or GSE tile shim, appeared to originate from the forward part of the body flap near the hinge line (E-5, -20).

Surface coating material was possibly missing in one spot on the base heat shield outboard of SSME #2 (OTV 050). Small pieces of tile surface coating material were lost during ignition from two places on the +Y APCS pod and one place on the –Y APCS pod (E-19, -20).

SSME ignition caused numerous pieces of ice from the LH2 ET/ORB umbilical to fall aft. Some pieces impacted the umbilical cavity sill, but no damage was visible. In addition, five pieces of mylar tape, the largest approximately 2-inches square, came loose from the forward area of the LH2 umbilical (OTV 009, 054, 063).

Vibration from SSME ignition caused the 4-inch by 3-inch ice/frost formation at the +Y vertical strut-to-ET acreage interface to fall aft (OTV 054).

The thermal short at the –Y bipod housing bondline was still venting at the time of liftoff. Three small pieces of ice from this same area fell aft without contacting flight hardware (E-40; OTV 061).

All views showing the +Y longeron with the four TPS surface cracks, which were detected prior to launch, confirmed no foam loss while in the field of view.

Just before T-0 at 17:43:36.844 UTC, a long, slender, white object, similar to a tie-wrap, was drawn across the field of view near the camera and moved in the direction of the SSME exhaust hole (E-8).

The stitching connecting two adjacent left SRB aft skirt thermal blankets was loose at a location in the general vicinity of HDP #6 (E-13).

No holddown post stud hang-ups occurred on this launch. No debris fell from the DCS stud holes (E7-14).

The GN2 purge lines separated cleanly from both SRB aft skirts at liftoff. The purge lines were visible for about two seconds after T-0. No anomalies were observed (E-8, -13).

Two tie-wraps fell from the LH2 T-0 carrier plate after retraction into the TSM at 17:43:41.064 and 17:43:41.516 UTC (E-22).

Two streaks occurred in the SSME #1 exhaust plume shortly after clearing the tower: one in the Mach diamonds at T+9.5 seconds MET and the second along the edge of the plume at T+10 seconds MET (TV-7).

Five streaks occurred in the SSME exhaust plume during early ascent in the SSME #1 plume at T+16 seconds MET, in the SSME #1 Mach diamonds at T+25 seconds MET, in the SSME #1 Mach diamonds at T+35 seconds MET and at T+40.5 seconds MET, and a very large flash in the SSME #1/#3 plume at T+43 seconds MET (TV-4). The large flash in the SSME exhaust plume at T+43.9 seconds MET (17:44:23.862 UTC) was also visible in film items E-222 and E-224. Two other flashes were timed at 17:44:06.379 and 17:44:13.425 UTC (E-222).

SRB tail-off and separation appeared normal. Slag falling out of the exhaust plume before, during and after SRB separation was typical (TV-4, TV-13).

6.1.2 SRB CAMERA VIDEO SUMMARY

The BI-100 SRB forward skirts were not configured to carry the 8mm video cameras on this flight.

Photo 16: Loose Thermal Curtain Stitching

The stitching connecting two adjacent left SRB aft skirt thermal blankets was loose at a location in the general vicinity of HDP #6.

6.2 ON-ORBIT FILM AND VIDEO SUMMARY

OV-105 was equipped to carry ET/ORB umbilical cameras: 16mm motion picture with 5mm lens and 16mm motion picture with 10mm lens from the LH2 side; 35mm still views from the LO2 side. The flight crew provided 35 still frames of hand-held imagery of the ET after separation. These frames captured prominent venting of hydrogen from the intertank relief valve – an expected occurrence. There was no camcorder video footage.

The SRB's and ET were silhouetted somewhat with the sun in the –Z direction during SRB separation. The vehicle had rolled to the heads-up position by the time the ET separated from the Orbiter. There was good frontal lighting on the ET after the Orbiter shadow moved away.

SRB separation from the External Tank appeared nominal. Illumination from the SRB exhaust plumes showed typical erosion/flaking of thin layers of TPS from the aft surfaces of the –Y upper strut fairing, -Y vertical strut, and LH2 ET/ORB cable tray. TPS charring and "popcorn" divoting of the aft dome was also typical.

The wide angle LH2 ET/ORB umbilical camera provided a view of the left SRB falling away from the ET and a partial view of the right SRB as seen under the ET cable tray. No anomalies were detected on either SRB including both nose caps.

ET-92 flown on this mission was a LWT configuration.

The ET TPS on the upper ogive near the nose cone, as well as the LOX tank, intertank, LH2 tank, and aft dome acreage, were all in excellent condition. The 12-inch by 12-inch TPS trim in the LOX tank was intact. No large divots were visible in either –Y or +Y thrust panel. The few, very small popcorn-type divots forward of the EB fittings were most likely caused by BSM exhaust plume impingement. No damage occurred on either LOX or LH2 ET/ORB umbilical interfaces. Although the viewing angle obscured some of the +Y longeron, no missing TPS was detected from the surface cracks created during cryoload.

The following is a list of local defects:

1. The long, thin, string-like object under the LH2 ET/ORB umbilical cable tray (visible during SRB separation and just before ET separation) is believed to be a long piece of the 1-inch wide mylar tape used to secure the umbilical purge barrier.

2. Blisters and a 10-inch by 10-inch area of missing surface rind on the +Y thrust strut. This phenomenon had not been seen before in this area.

3. Three divots on the press line ramp upper closeout, station XT-1722.

4. One divot approximately 18-inches long at the +Y thrust panel to stringer interface just forward of the LH2 tank-to-intertank flange.

5. One 18-inch by 6-inch divot to the +Y side of the LH2 tank cable tray. The divot extended from the LH2 tank-to-intertank flange closeout into the intertank net spray foam.

6. One 7-inch by 5-inch divot at the LH2 tank-to-intertank flange closeout on centerline between the bipods. Substrate was visible in the cavity. Note: both bipod jack pad stand-off closeouts were intact.

7. Two adjacent 6-7 inch diameter divots in the LH2 tank-to-intertank flange closeout in the –Y+Z quadrant outboard of the –Y bipod housing.

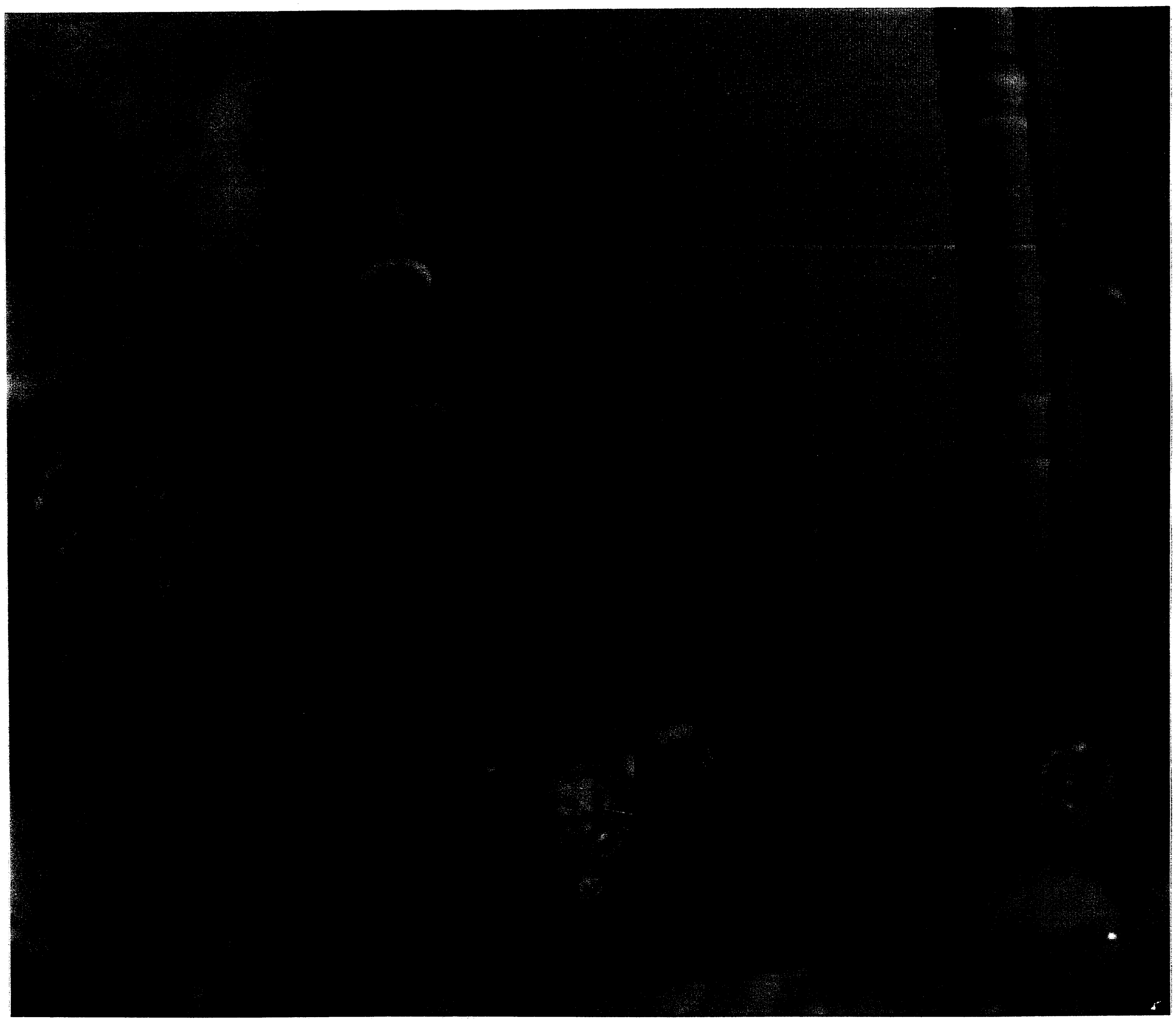


Photo 17: ET After Separation

There was no apparent damage to the ET/ORB umbilicals. No impact damage and less than usual erosion occurred on the –Y thrust strut. Note frozen hydrogen in the 17-inch flapper valve (arrow) and ice/frost formation near the transportation fitting (arrow).

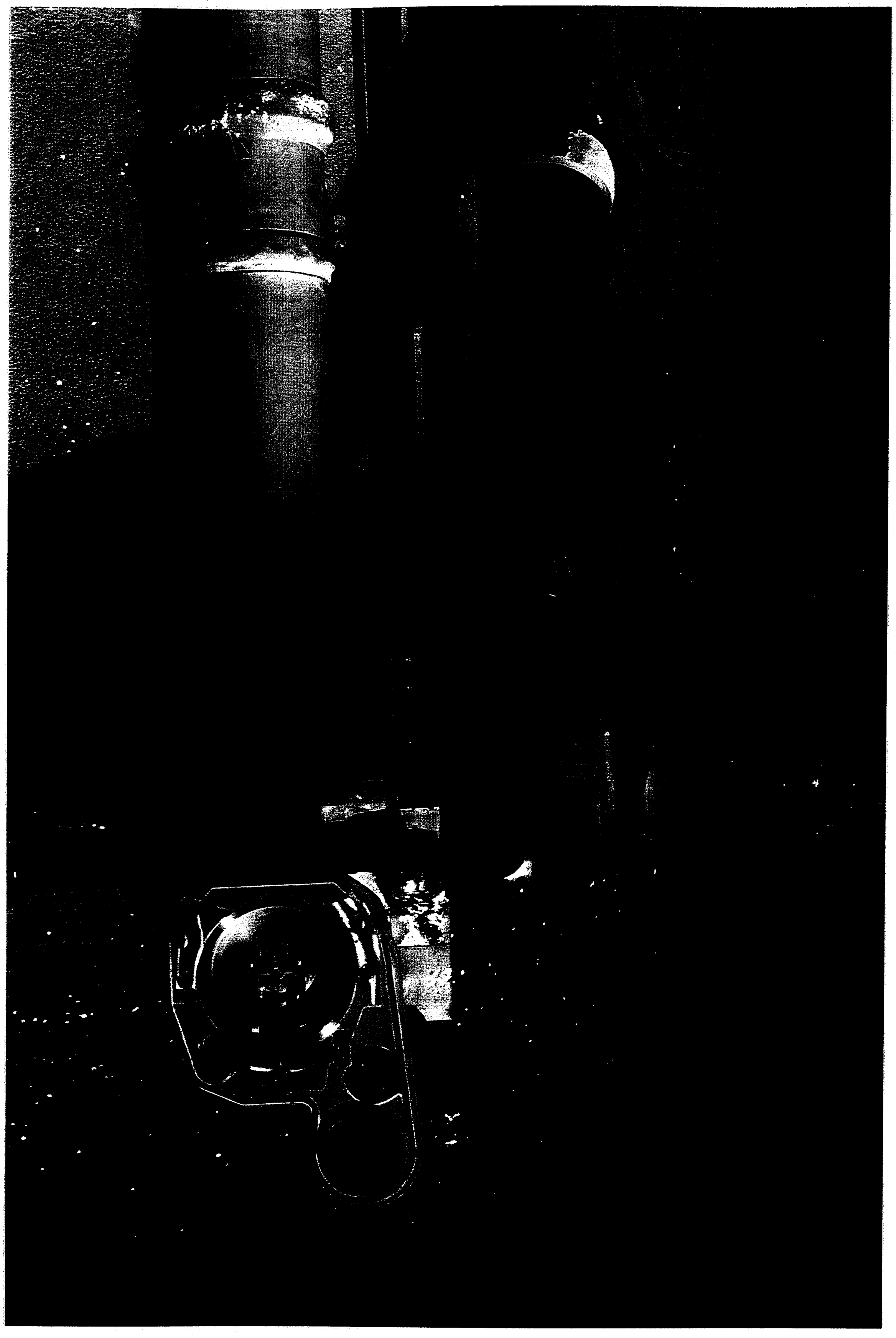


Photo 18: LH2 Tank after Separation

There was no damage to the LO2 ET/ORB umbilical except for typical erosion of cable tray TPS. Erosion of TPS on the LO2 feedline flange closeout was also typical. Note ice still remaining in feedline bellows. Blisters and a 10-inch by 10-inch area of missing surface rind were detected on the +Y thrust strut. This phenomenon had not been seen before in this area. Also, the TPS in the area of the longeron closeout cracks appeared to be intact.

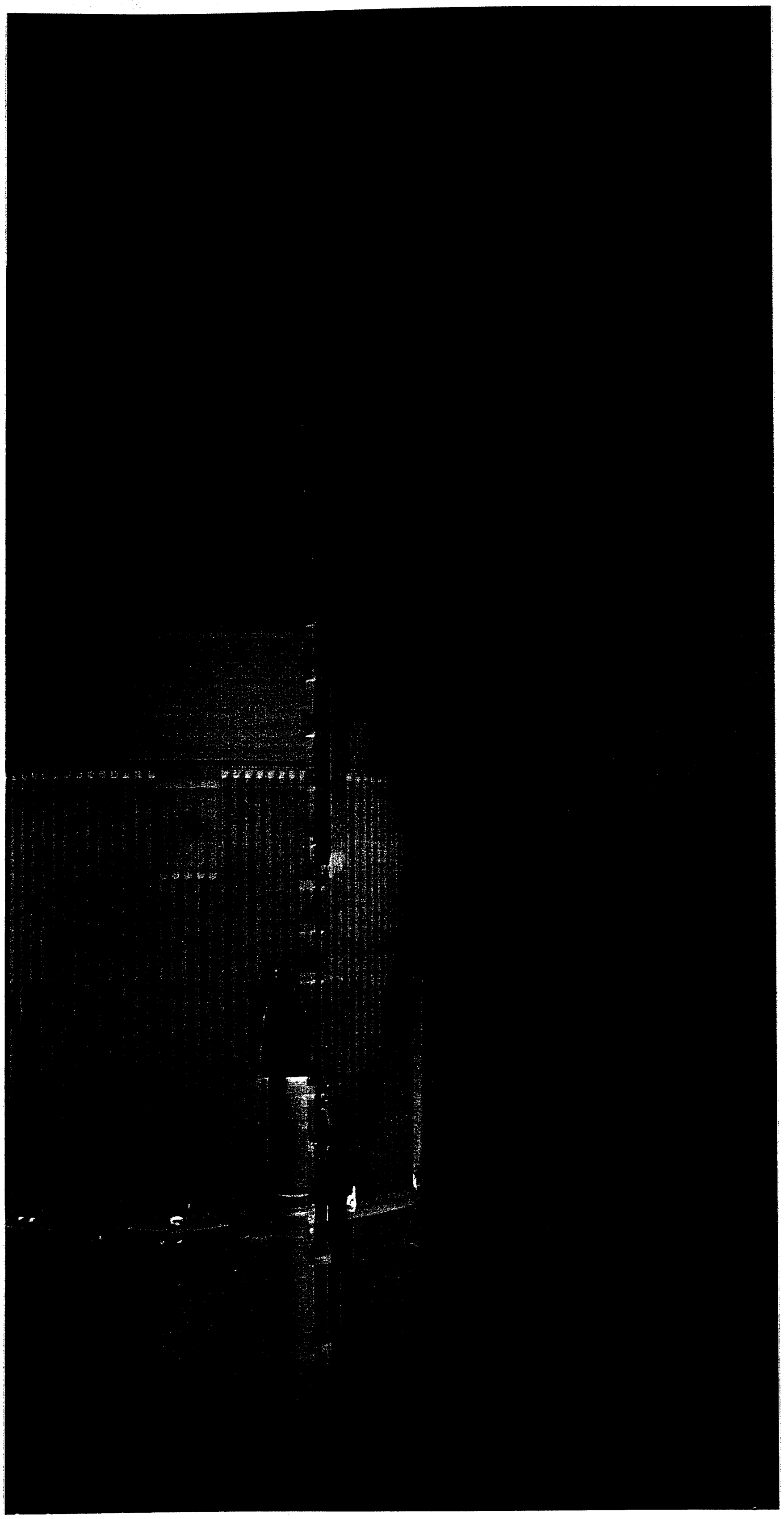


Photo 19: ET After Separation

The ET TPS on the upper ogive near the nose cone, as well as the LOX tank and intertank were all in excellent condition. The 12-inch by 12-inch TPS trim in the LOX tank was intact. No large divots were visible in the +Y thrust panel. Divots occurred at the +Y thrust panel to stringer interface just forward of the LH2 tank-to-intertank flange, to the +Y side of the LH2 tank cable tray, at the LH2 tank-to-intertank flange closeout on centerline between the bipods, and in the LH2 tank-to-intertank flange closeout in the –Y+Z quadrant outboard of the –Y bipod housing (arrows).

Photo 20: ET –Y Thrust Panel

No large divots or unusual erosion was visible in the –Y thrust panel foam. The BSM burn scar forward of the EB fitting and on the LO2 tank was typical.

6.3 LANDING FILM AND VIDEO SUMMARY

A total of 20 films and videos, which included eight 35mm large format films, two 16mm high speed films, and ten videos, were reviewed. There was not much detail for engineering assessment due to the dark conditions of a night landing.

The landing gear extended properly. The infrared scanners showed no debris falling from the Orbiter during final approach.

Runway centerline cameras showed right wing low during final approach to counteract the effects of the crosswind. The Orbiter touched down east of centerline, then was soon corrected to roll back on runway centerline.

Drag chute deployment, which occurred after the nose wheel contacted the runway, appeared normal. No anomalies were detected from touch down through rollout.

A somewhat unusual event had occurred on the STS-103 mission. The infrared signature of the three main engines during touchdown and rollout showed the SSME #2 nozzle warmer than the nozzles on SSME #1 and #3. However, no anomalies were detected to explain the difference. This phenomenon did not occur on the STS-99 landing and all three SSME nozzles appeared to have similar temperatures.

7.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-100 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAFS Hangar AF on 14 February 2000. Both boosters were in excellent condition. Regarding both left and right SRB's:

The frustums exhibited no debonds/unbonds or missing TPS.

All eight BSM aero heat shield covers had locked in the fully opened position though the left two cover attach rings on the left frustum had been deformed by the parachute risers.

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact.

The Field Joint Protection System (FJPS) and the System Tunnel Covers closeouts were generally in good condition with no unbonds.

Separation of the aft ET/SRB struts appeared normal.

Aft skirt external surface TPS was nominal and in good condition. Typical blistering of Hypalon paint had occurred on the BTA insulation closeouts.

The holddown post Debris Containment Systems (DCS) appeared to have functioned normally.

The HDP #5 DCS plunger was fully obstructed by the frangible nut halves. This condition most likely happened at water impact.

There was no evidence of a stud hang-up on this launch.

Overall, the external condition of both SRB's was excellent.

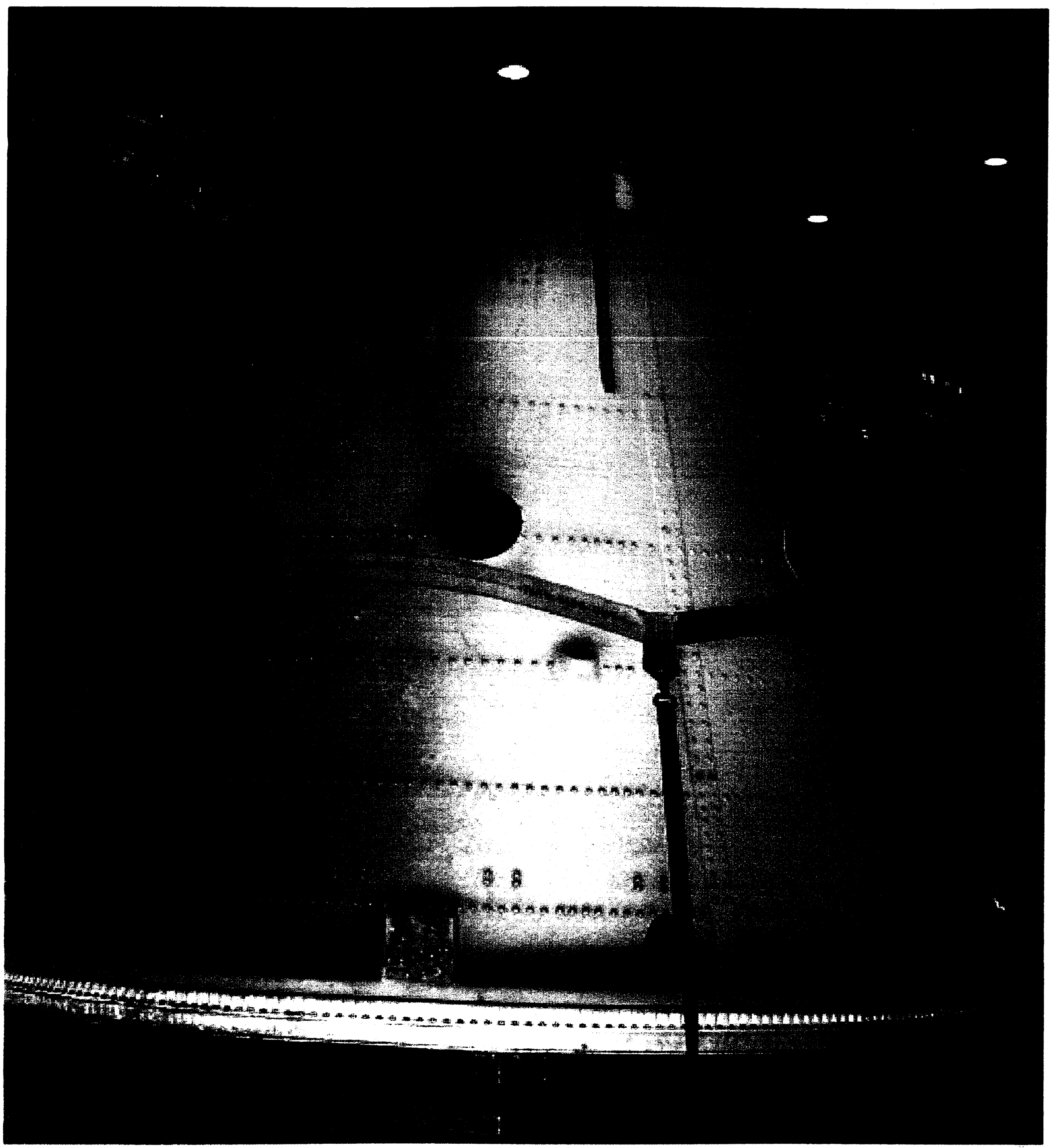
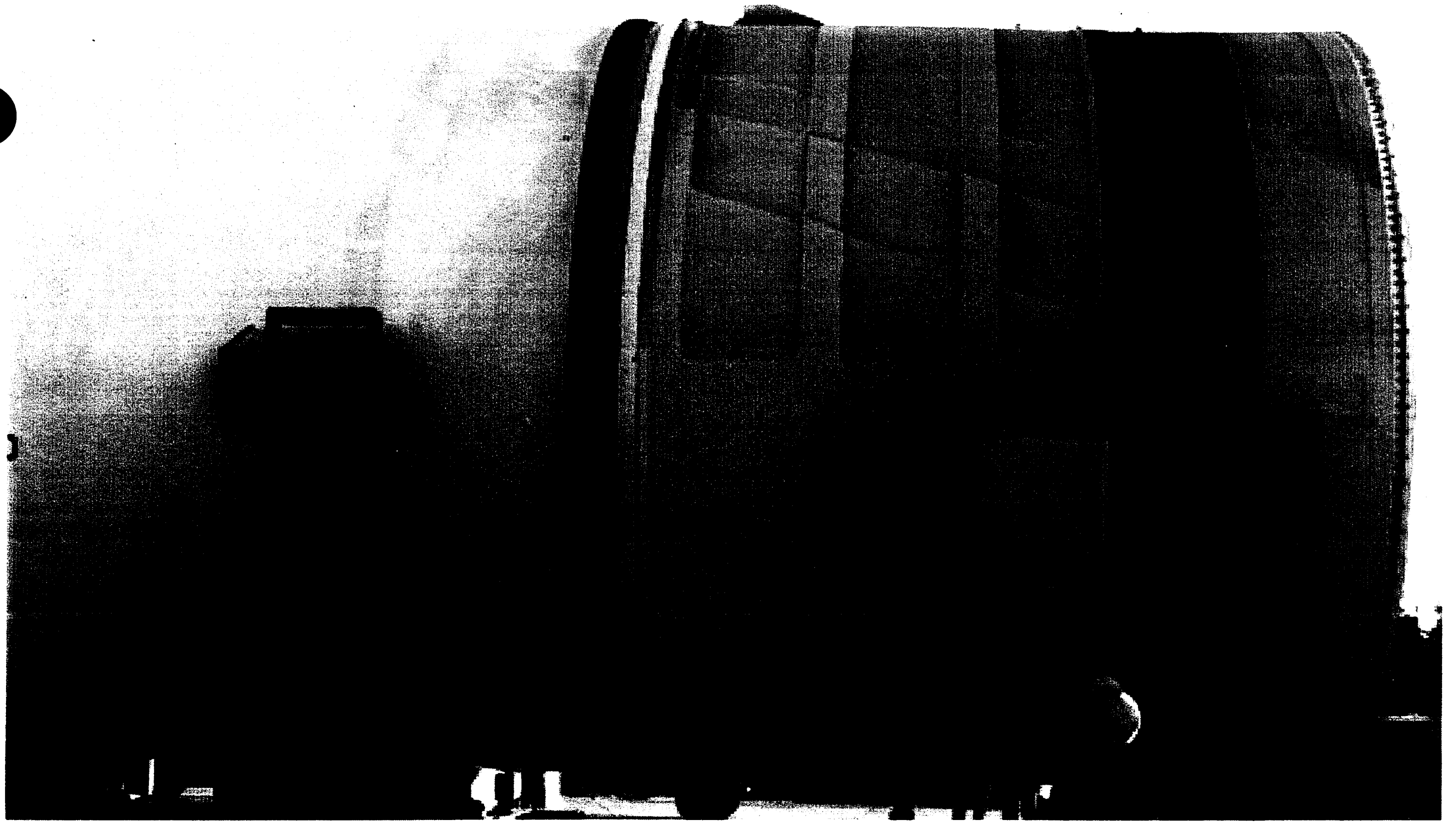


Photo 21: Frustum Post Flight Condition

The frustums exhibited no debonds/unbonds or missing TPS. All eight BSM aero heat shield covers had locked in the fully opened position though the left two cover attach rings on the left frustum had been deformed by the parachute risers.



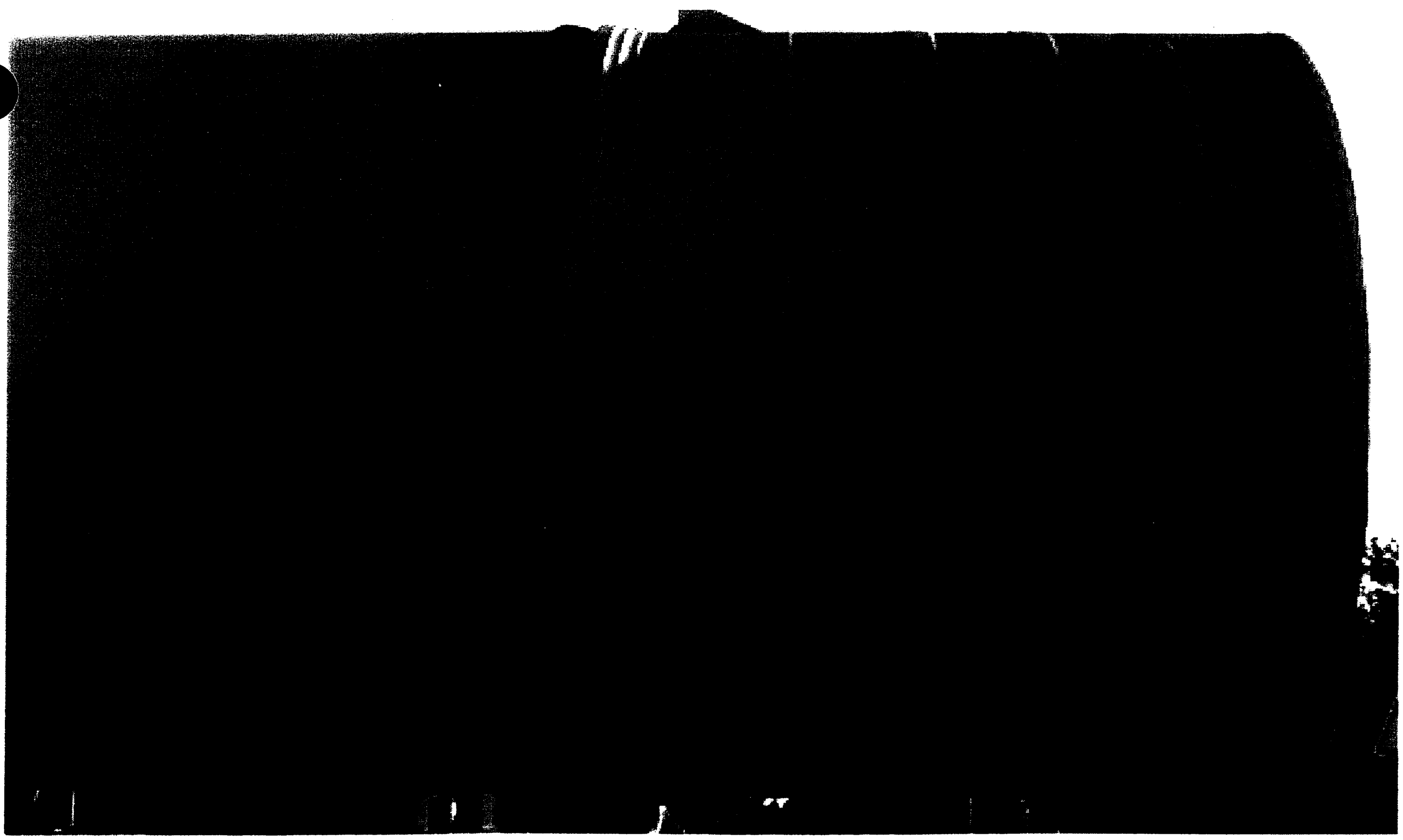


Photo 22: Forward Skirt Post Flight Condition

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact.

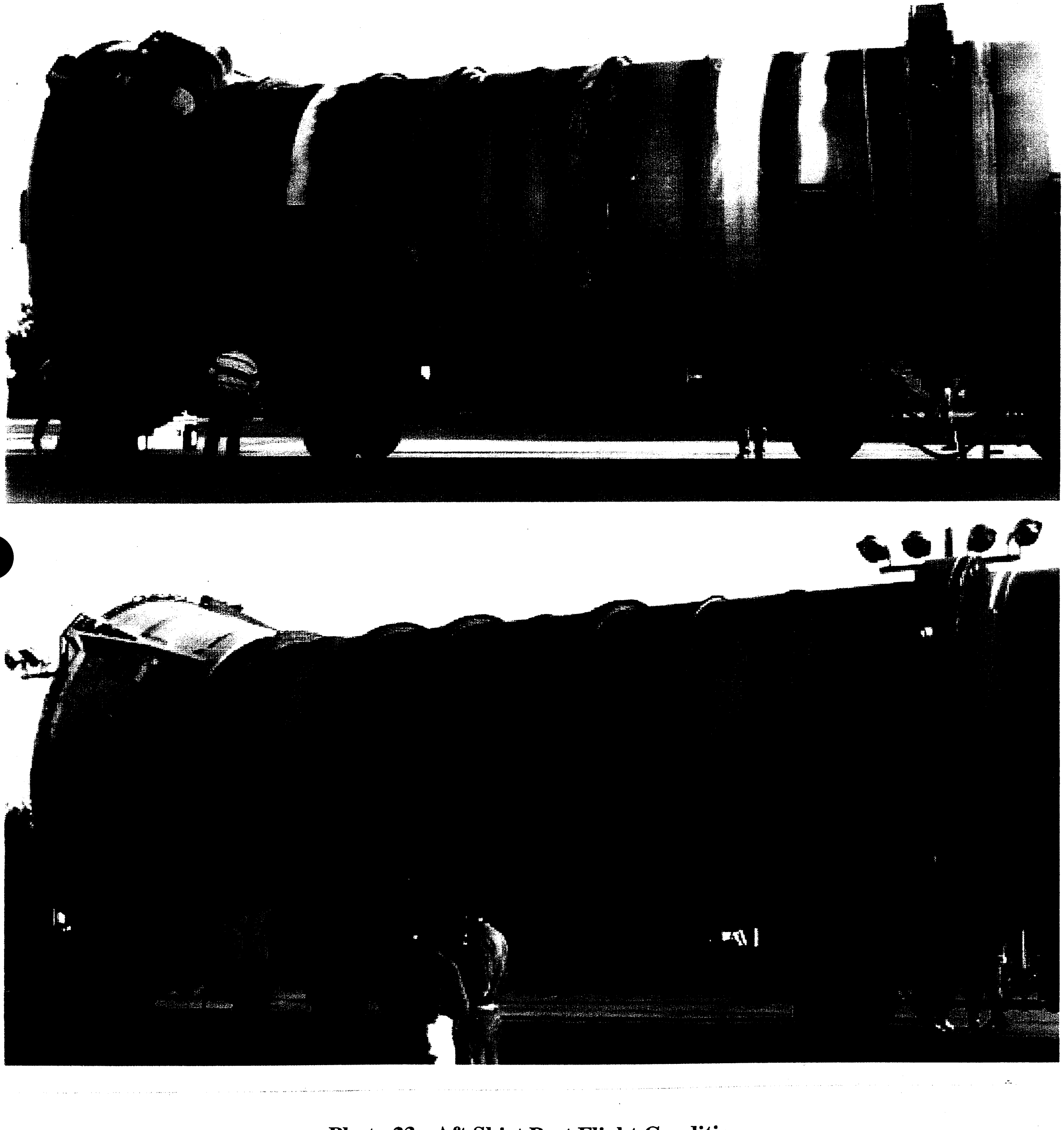


Photo 23: Aft Skirt Post Flight Condition

Aft skirt external surface TPS was nominal and in good condition

8.0 ORBITER POST LANDING DEBRIS ASSESSMENT

After the 6:22 p.m. local/eastern time landing on 22 February 2000, a post landing inspection of OV-105 Endeavour was conducted at the Kennedy Space Center on SLF runway 33 and in the Orbiter Processing Facility bay #2. This inspection was performed to identify debris impact damage and, if possible, debris sources.

The Orbiter TPS sustained a total of 88 hits, of which 25 had a major dimension of 1-inch or larger. This total does not include the numerous hits on the base heat shield attributed to SSME vibration/acoustics and exhaust plume recirculation (Reference Figures 1-3. No hits occurred on the left side of the Orbiter and the associated figure has been omitted. For comparison purposes, Figure 4 shows fleet averages prior to STS-86 when loss of ET thrust panel foam began).

The following table breaks down the STS-99 Orbiter debris damage hits by area:

	HITS > 1"	TOTAL HITS
Lower surface	21	75
Upper surface	0	0
Window Area	2	10
Right side	1	1
Left side	0	0
Right OMS Pod	0	0
Left OMS Pod	1	2
TOTALS	25	88

The Orbiter lower surface sustained 75 total hits, of which 21 had a major dimension of 1-inch or larger. Approximately half of this damage was concentrated from the nose gear to the main landing gear wheel wells with more hits on the left chine than on the right. In general, the lower surface tile damage on this flight is considered In Family though the damage followed a pattern similar to that documented on flights STS-86 to STS-103. ET-92 was a LWT configuration with the venting modification performed only on the +Z side of the thrust panels. Because of the LWT configuration, the TPS on the +Z intertank stringers was not vented.

The longest, and deepest, lower surface tile damage site was located just forward of the LH2 ET/ORB umbilical, spanned three tiles, and measured 4-inches long by 2-inches wide by 0.75-inches deep. Most of the damage sites forward of the main landing gear wheel wells did not exceed an 1/8-inch depth, though there were three locations that measured ¼-inch deep.

Tile damage sites around the LH2 and LO2 ET/ORB umbilicals were greater in number and size than usual. This damage was caused by contact with shredded pieces of umbilical purge barrier material flapping in the airstream.

The main landing gear tires were reported to be in good condition for a landing on the KSC concrete runway. Ply under cutting was observed on both LH main landing gear tires and on the RH inboard tire.

ET/Orbiter separation devices EO-1, EO-2, and EO-3 functioned normally. No ordnance fragments were found on the runway beneath the ET/ORB umbilicals. The EO-2 and EO-3 fitting retainer springs appeared to be in nominal configuration. No umbilical closeout foam or white RTV dam material adhered to the umbilical plate near the LH2 recirculation line disconnect.

Less than usual amounts of tile damage occurred on the base heat shield. All SSME Dome Heat Shield closeout blankets were in good condition though some material was torn/frayed at the 6:00 o'clock position on SSME #1 and the 3:00 o'clock position on SSME #2.

No unusual tile damage occurred on the leading edges of the OMS pods and vertical stabilizer.

Damage sites on the window perimeter tiles was less than usual in quantity and size. Hazing and streaking of forward-facing Orbiter windows was moderate. There were 10 hits with two larger than 1-inch in the vicinity of the windows. This damage may be attributed to impacts from FRCS thruster paper covers and the RTV adhesive.

The post landing walkdown of Runway 33 was performed immediately after landing. A rudder/speed brake seal metal clip 2.5-inches long by 1-inch wide was recovered 8 feet east of runway centerline at the 3800 foot marker. All components of the drag chute were recovered and appeared to have functioned normally. Both reefing line cutter pyrotechnic devices were expended.

In summary, the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger were "in family". However, the twenty-five lower surface hits 1-inch or larger were close to the 3-sigma upper control limit of 29 (Figures 5-8). The control charts reflect a comparative family from STS-70 through STS-85 where debris control measures had been optimized and debris damage sites on the Orbiter minimized to a family of flights beginning with STS-86 and the loss of foam from ET thrust panels.

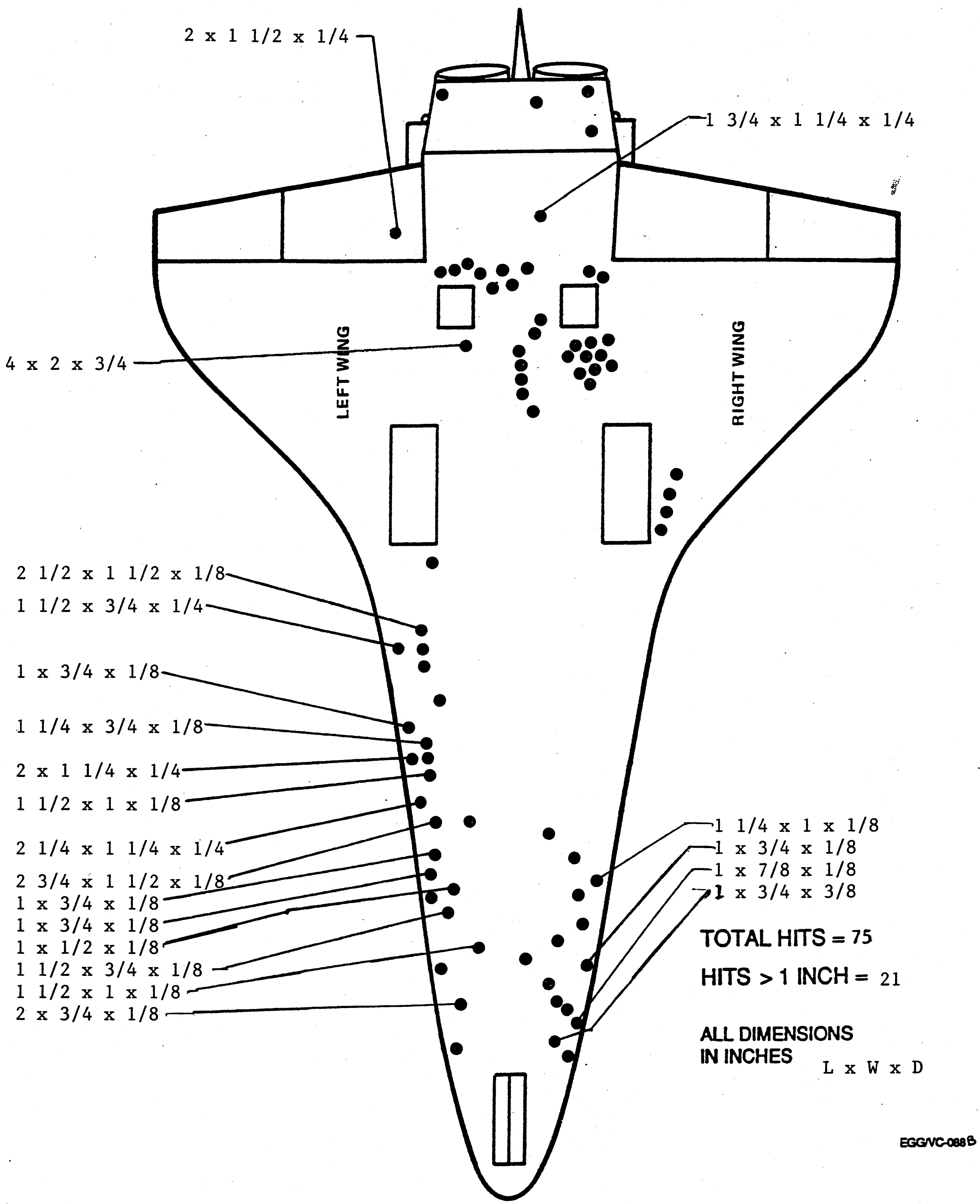


Figure 1: Orbiter Lower Surface Debris Damage Map

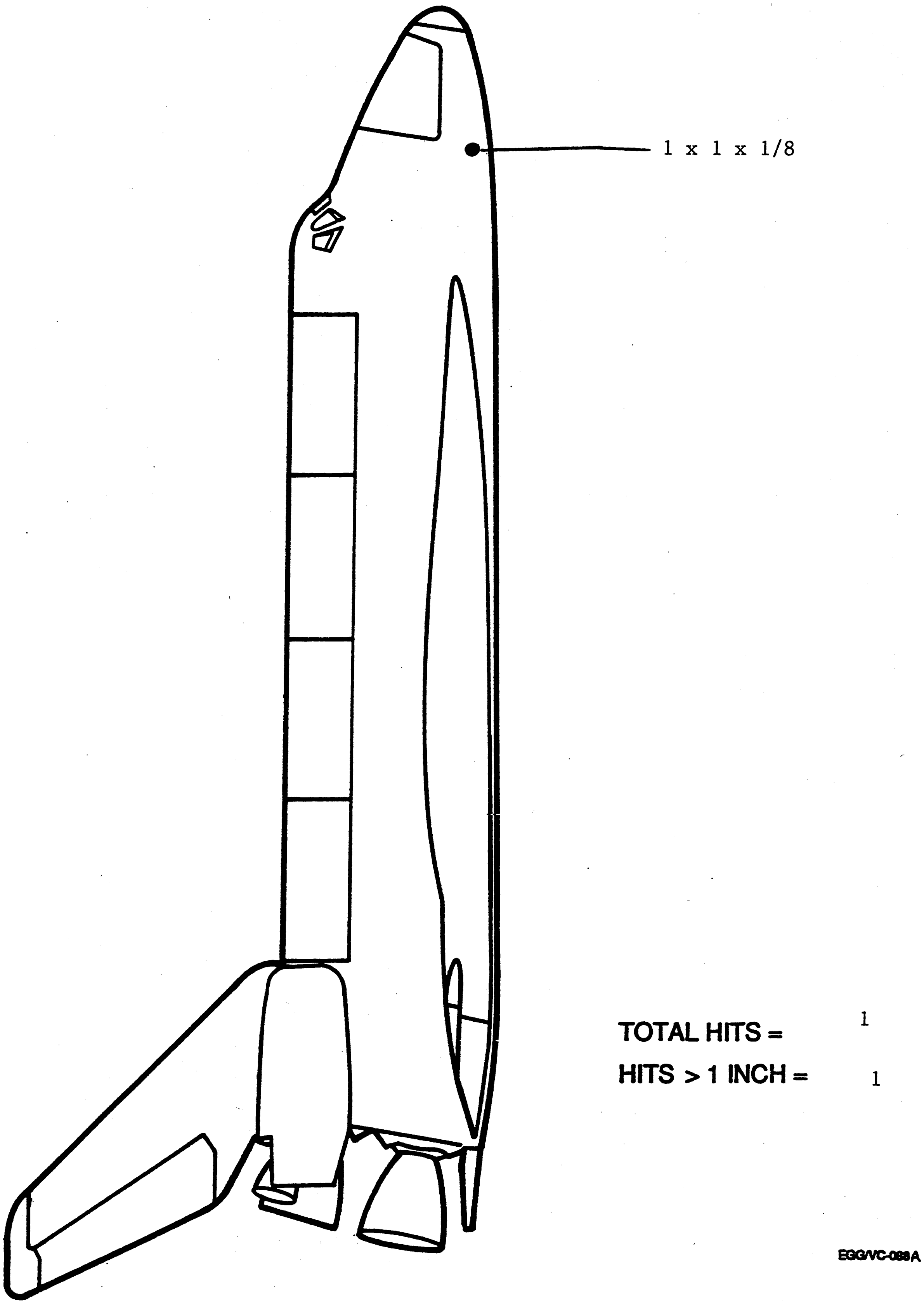


Figure 2: Orbiter Right Side Debris Damage Map

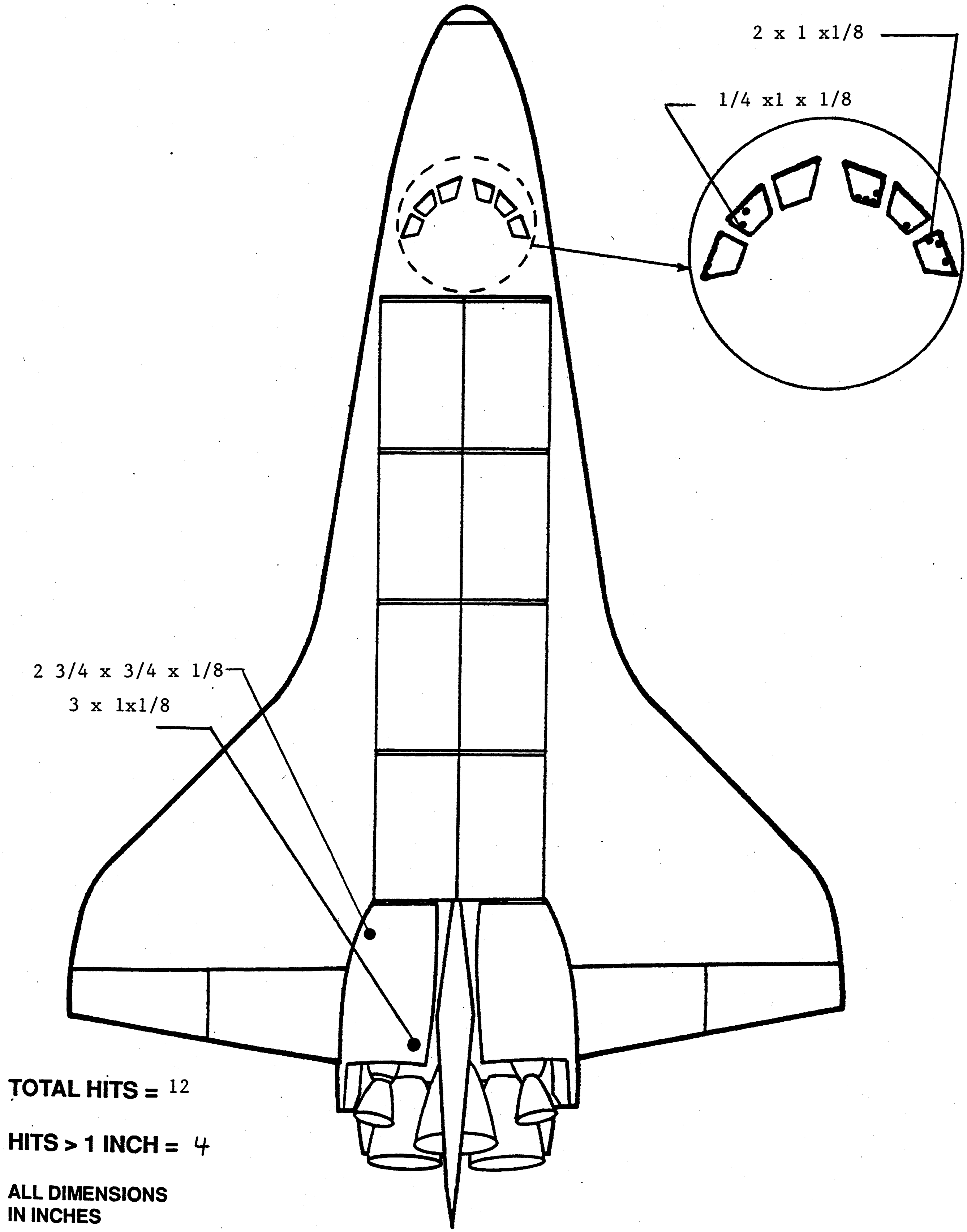


Figure 3: Orbiter Upper Surface Debris Damage Map

Figure 4: Orbiter Post Flight Debris Damage Summary

	LOWER SURFACE		ENTIRE SURFACE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
STS-6	21	89	36	120
STS-8	3	29	7	56
STS-9 (41-A)	9	49	14	58
STS-11 (41-B)	11	19	34	63
STS-13 (41-C)	5	27	8	36
STS-14 (41-D)	10	44	30	111
STS-17 (41-G)	25	69	36	154
STS-19 (51-A)	14	66	20	87
STS-20 (51-C)	24	67	28	81
STS-27 (51-I)	21	96	33	141
STS-28 (51-J)	7	66	17	111
STS-30 (61-A)	24	129	34	183
STS-31 (61-B)	37	177	55	257
STS-32 (61-C)	20	134	39	193
STS-29	18	100	23	132
STS-28R	13	60	20	76
STS-34	17	51	18	53
STS-33R	21	107	21	118
STS-32R	13	111	15	120
STS-36	17	61	19	81
STS-31R	13	47	14	63
STS-41	13	64	16	76
STS-38	7	70	8	81
STS-35	15	132	17	147
STS-37	7	91	10	113
STS-39	14	217	16	238
STS-40	23	153	25	197
STS-43	24	122	25	131
STS-48	14	100	25	182
STS-44	6	74	9	101
STS-45	18	122	22	172
STS-49	6	55	11	114
STS-50	28	141	45	184
STS-46	11	186	22	236
STS-47	3	48	11	108
STS-52	6	152	16	290
STS-53	11	145	23	240
STS-54	14	80	14	131
STS-56	18	94	36	156

	LOWER SURFACE		ENTIRE SURFACE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
STS-55	10	128	13	143
STS-57	10	75	12	106
STS-51	8	100	18	154
STS-58	23	78	26	155
STS-61	7	59	13	120
STS-60	4	48	15	106
STS-62	7	36	16	97
STS-59	10	47	19	77
STS-65	17	123	21	151
STS-64	18	116	19	150
STS-68	9	59	15	110
STS-66	22	111	28	148
STS-63	7	84	14	125
STS-67	11	47	13	76
STS-71	24	149	25	164
STS-70	5	81	9	127
STS-69	22	175	27	198
STS-73	17	102	26	147
STS-74	17	78	21	116
STS-72	3	23	6	55
STS-75	11	55	17	96
STS-76	5	32	15	69
STS-77	15	48	17	81
STS-78	5	35	12	85
STS-79	8	65	11	103
STS-80	4	34	8	93
STS-81	14	48	15	100
STS-82	14	53	18	103
STS-83	7	38	13	81
STS-84	10	67	13	103
STS-94	11	34	12	90
STS-85	6	37	13	102
AVERAGE	13.3	83.2	19.6	124.3
SIGMA	7.1	43.9	9.5	51.9
STS-99	21	75	25	88

MISSIONS STS-23,24,25,26,26R,27R,30R,42,86,87,89,90,91,95,88,96 AND 93 ARE NOT INCLUDED SINCE THESE MISSIONS HAD SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS SOURCES

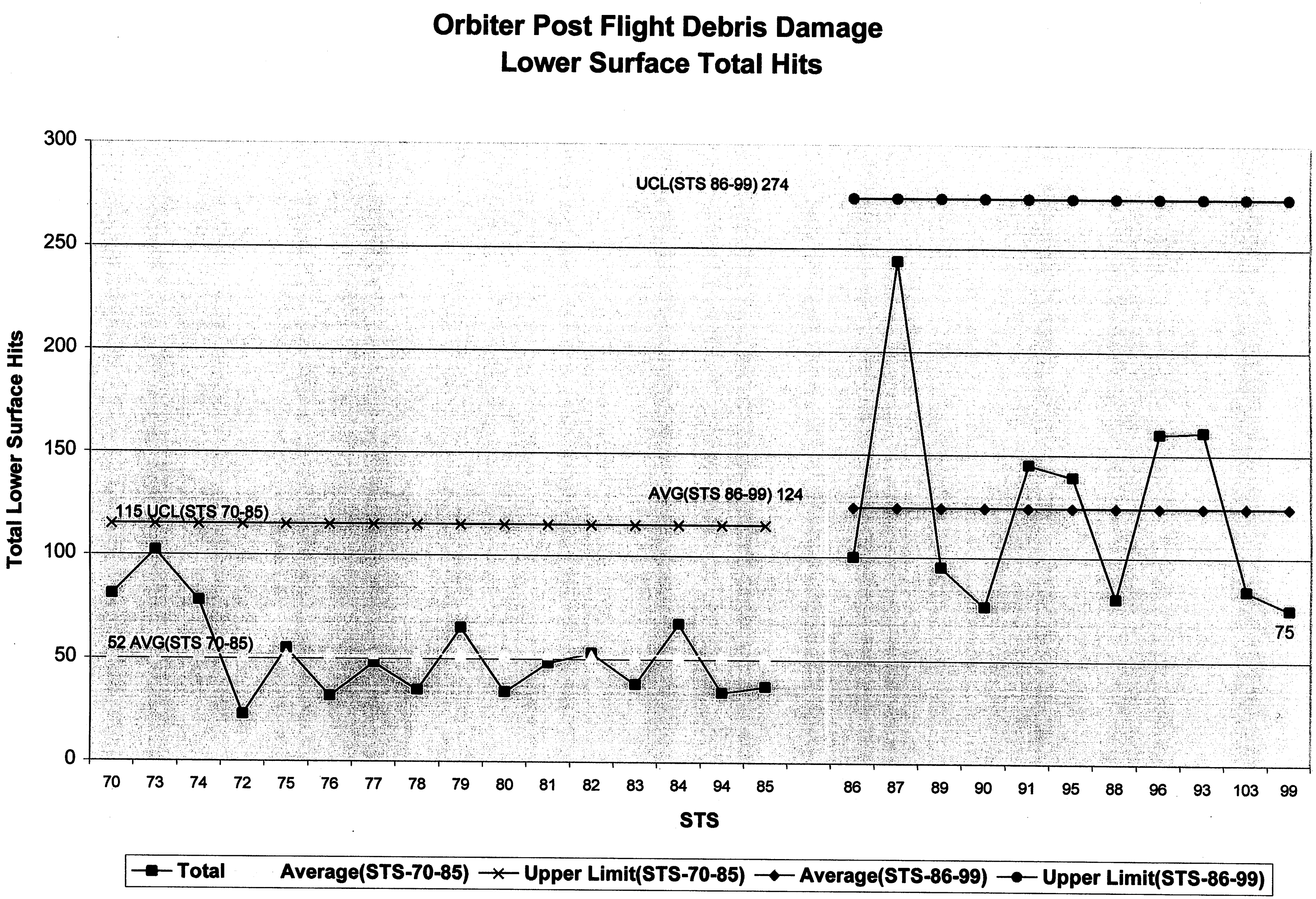


Figure 5: Control Limits for Lower Surface Total Hits

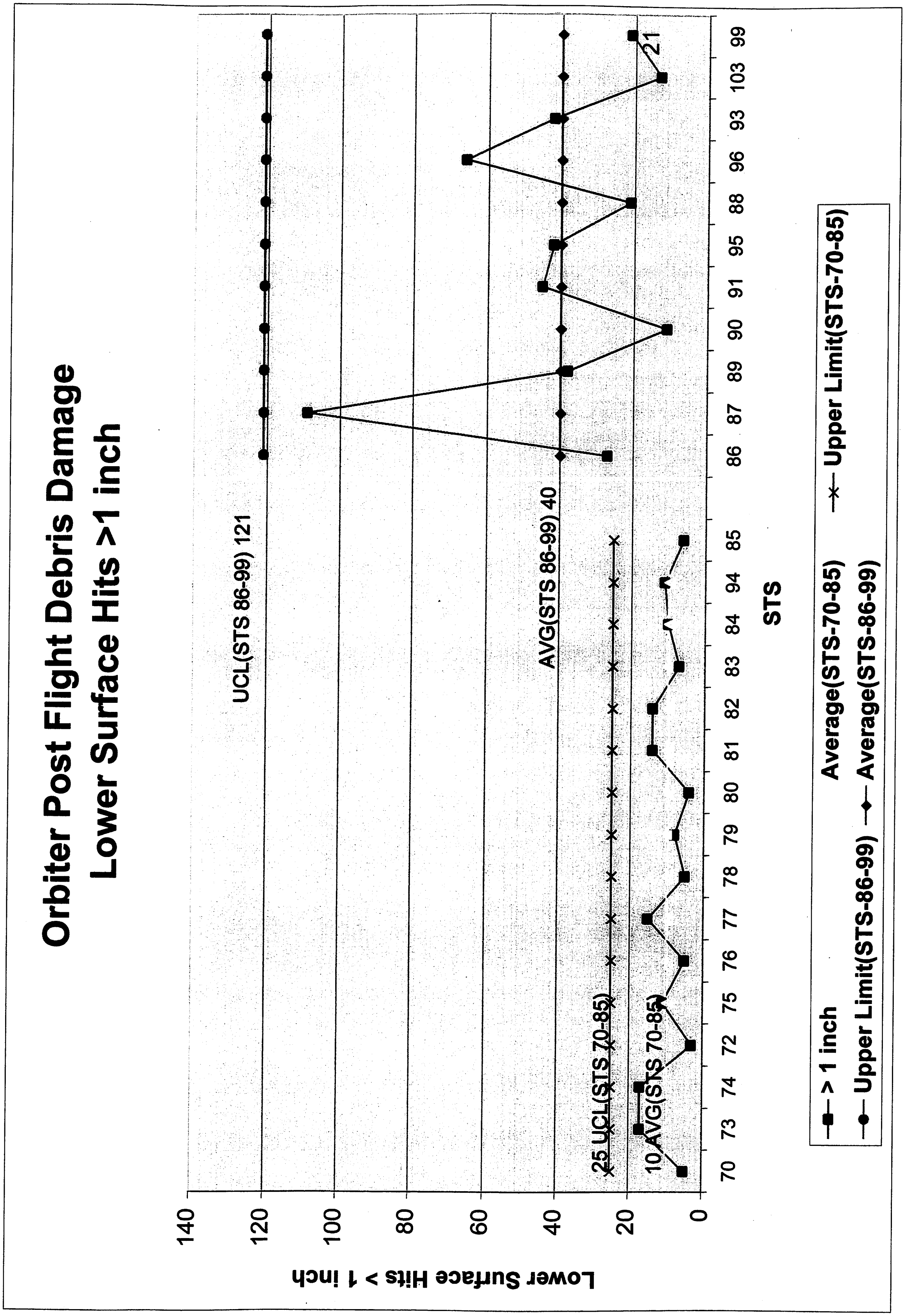


Figure 6: Control Limits for Lower Surface Hits > 1-inch

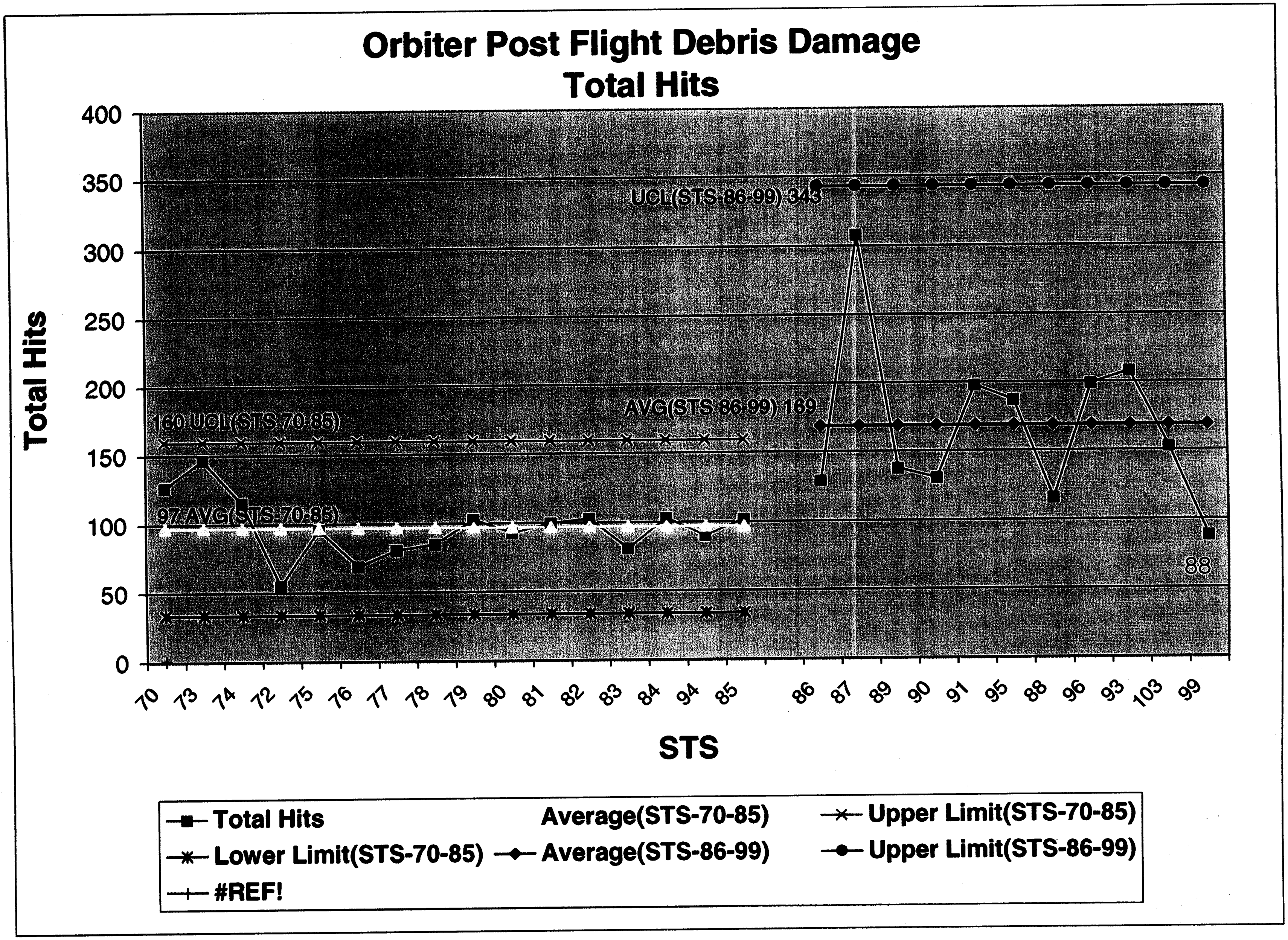


Figure 7: Control Limits for Total Hits

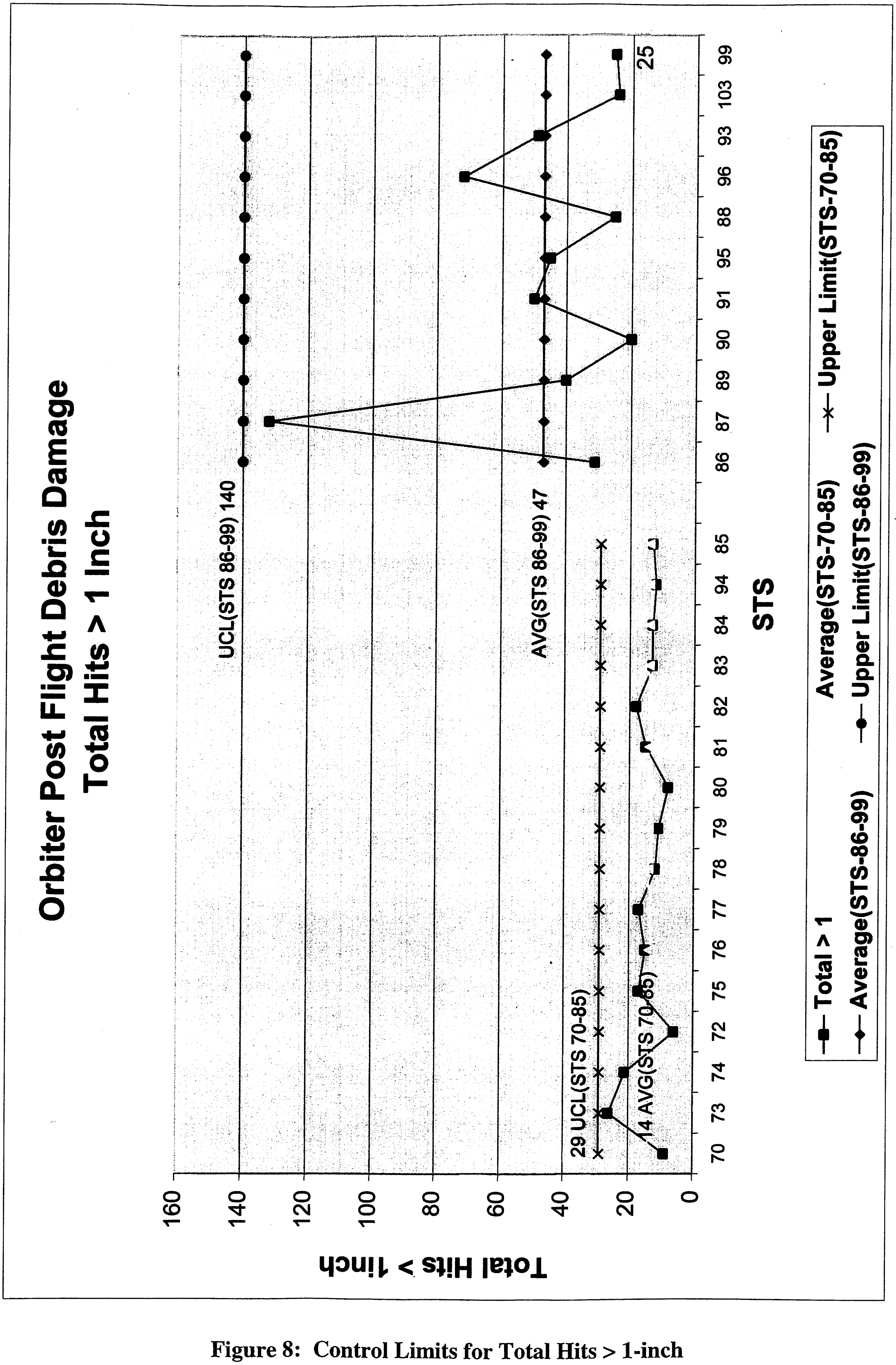


Figure 8: Control Limits for Total Hits > 1-inch

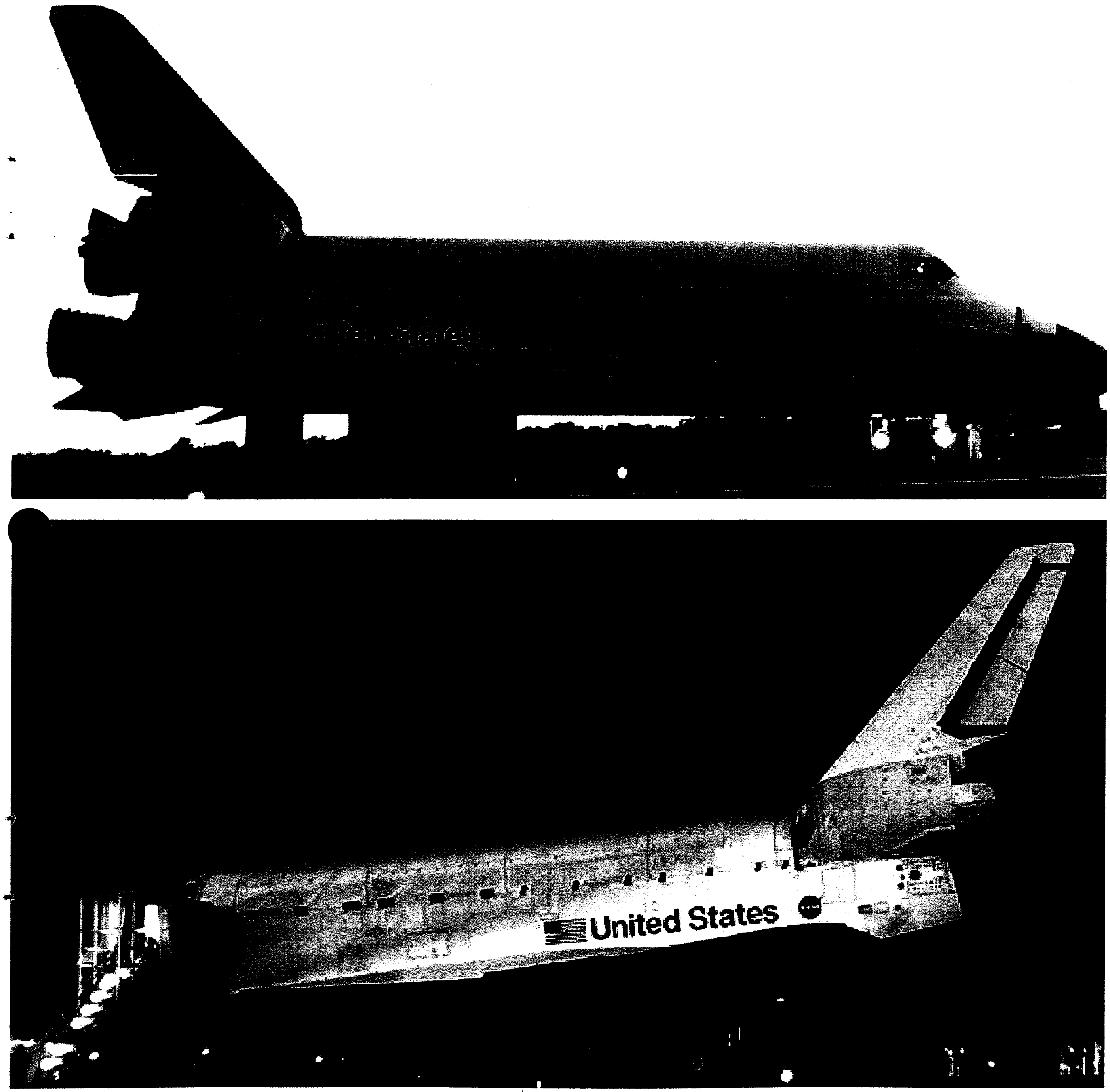


Photo 24: Overall View of Orbiter Sides

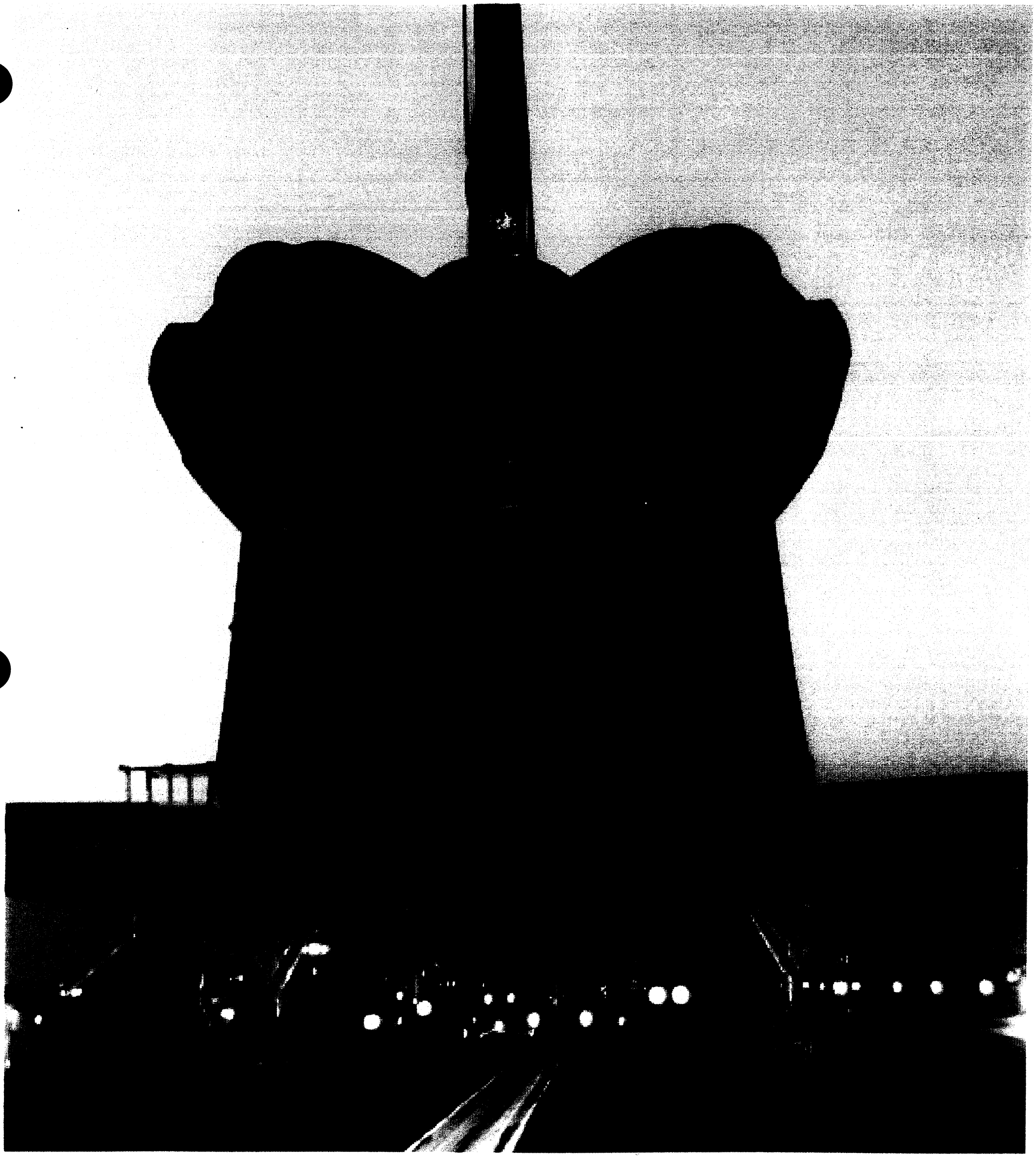


Photo 25: SSME's and Base Heat Shield

Less than usual amounts of tile damage occurred on the base heat shield. All SSME Dome Heat Shield closeout blankets were in good condition though some material was torn/frayed at the 6:00 o'clock position on SSME #1 and the 3:00 o'clock position on SSME #2.

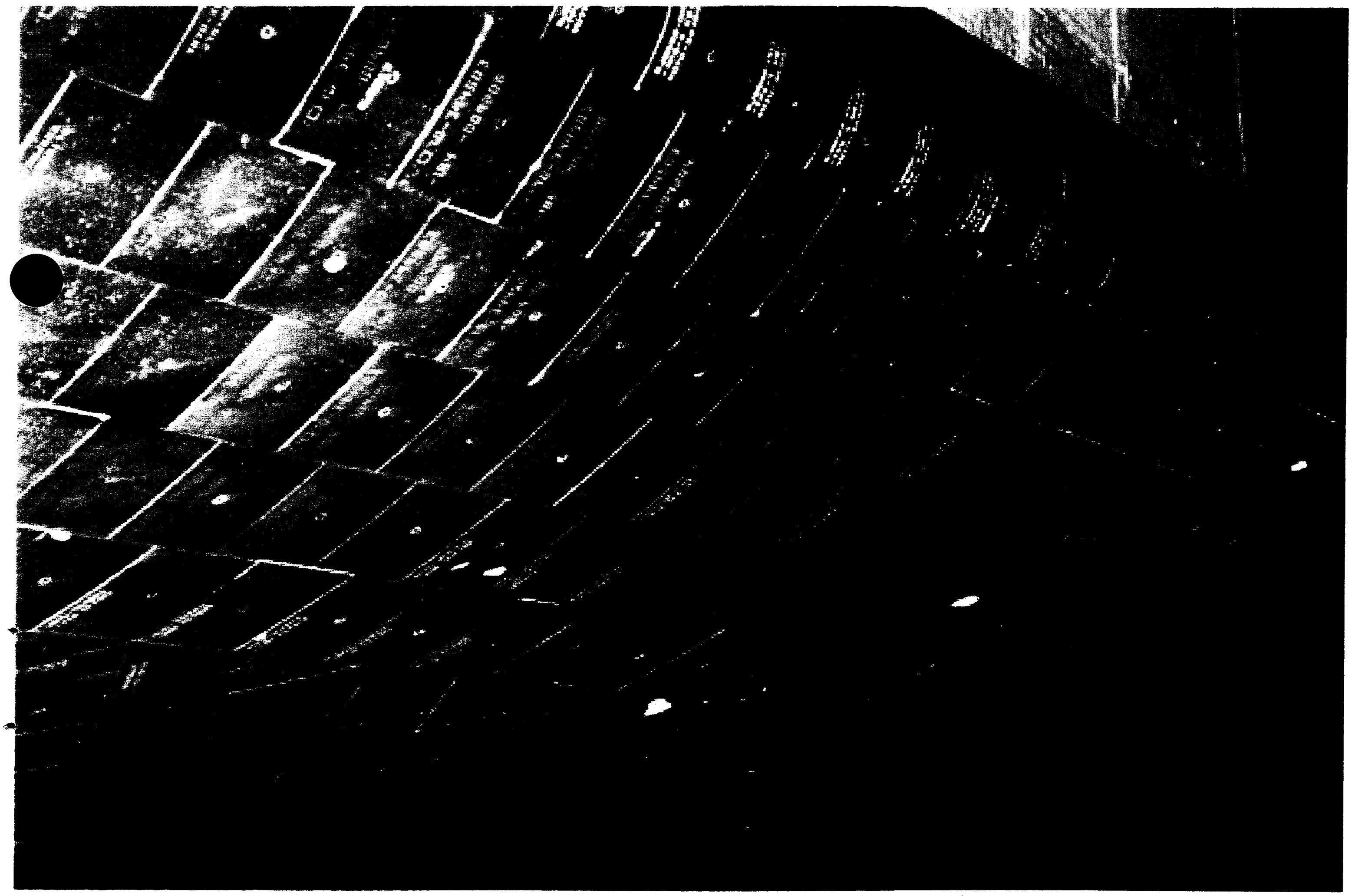


Photo 26: Damage to Lower Surface Tiles

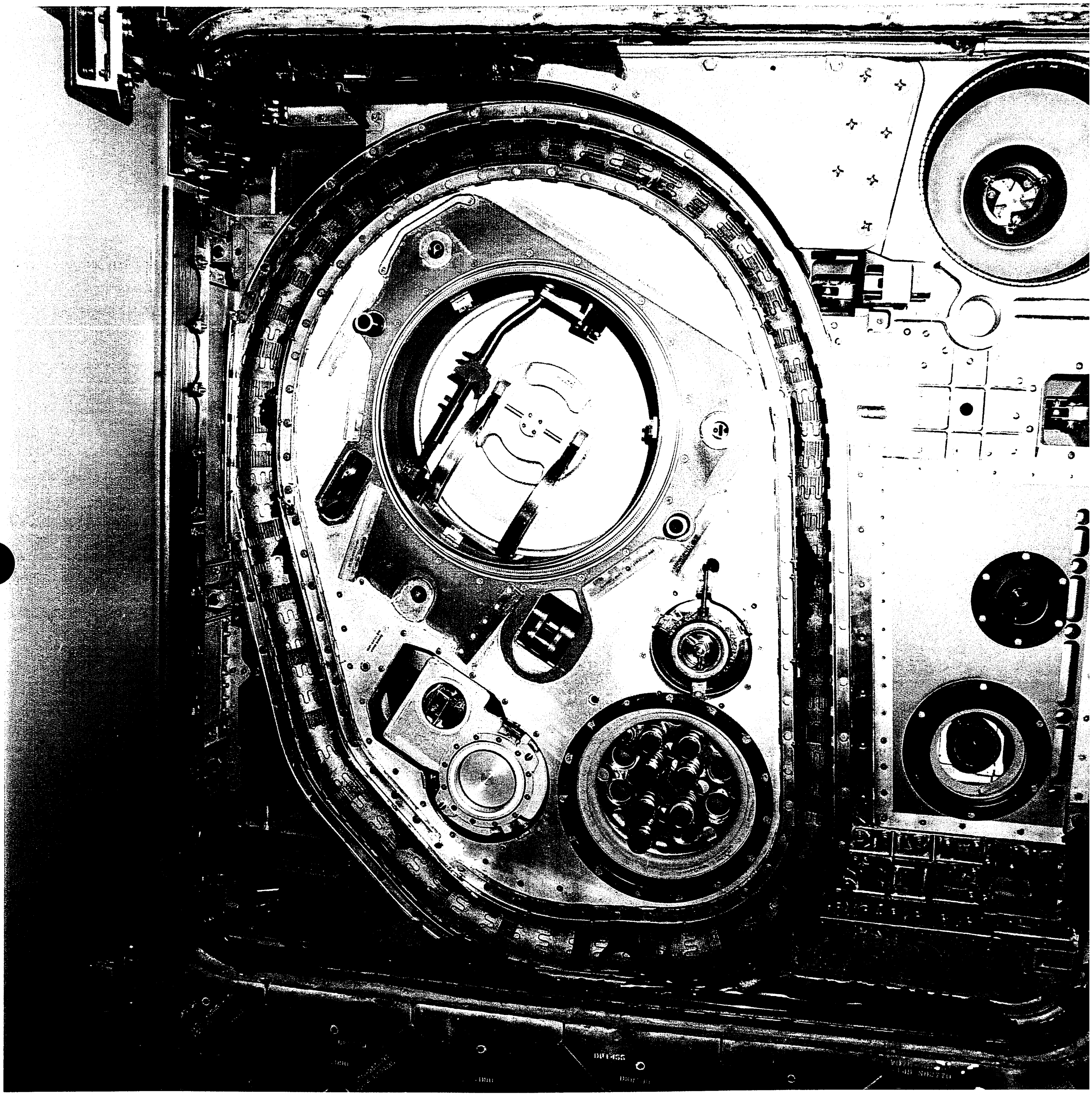


Photo 27: LH2 ET/ORB Umbilical

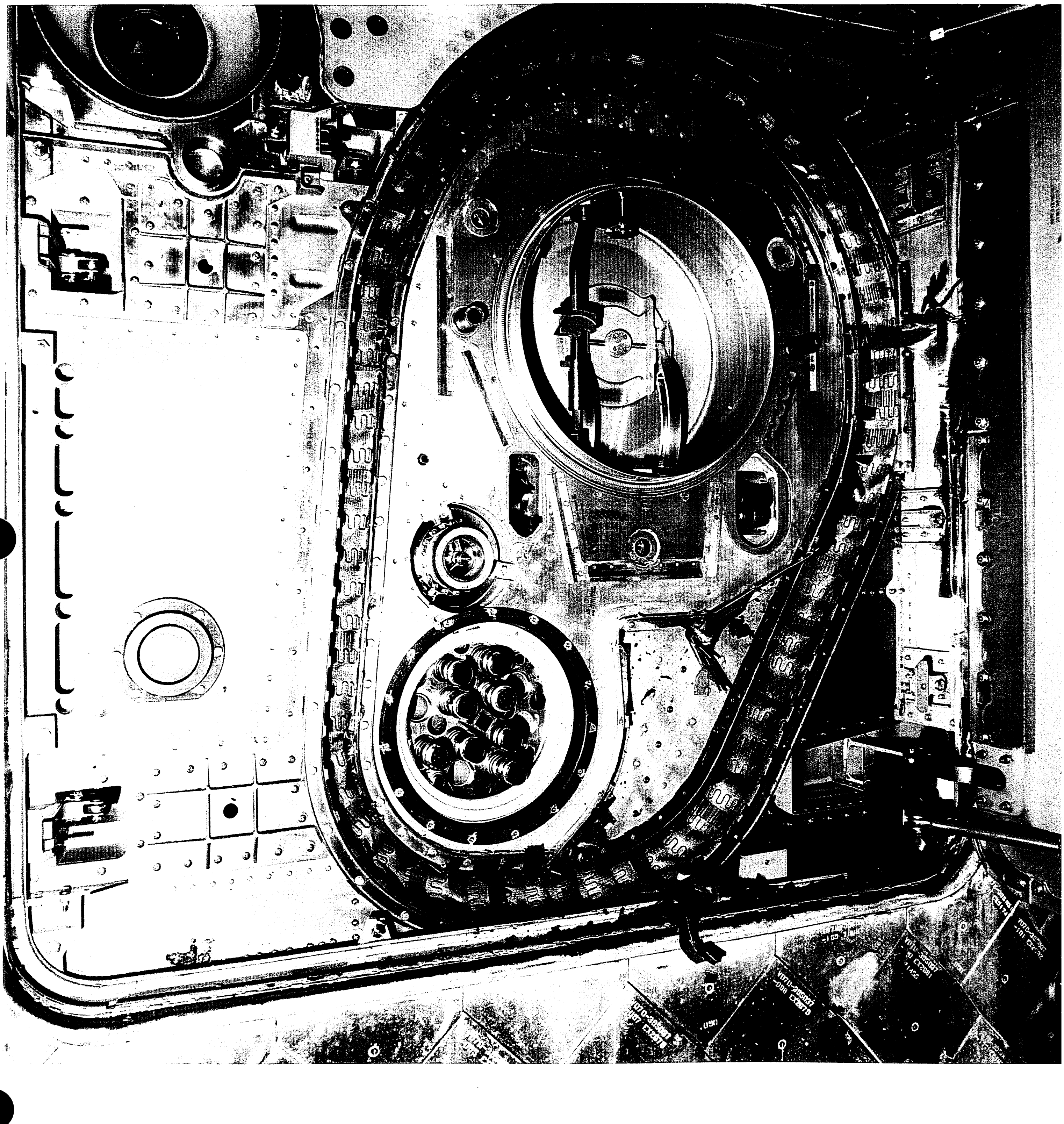


Photo 28: LO2 ET/ORB Umbilical

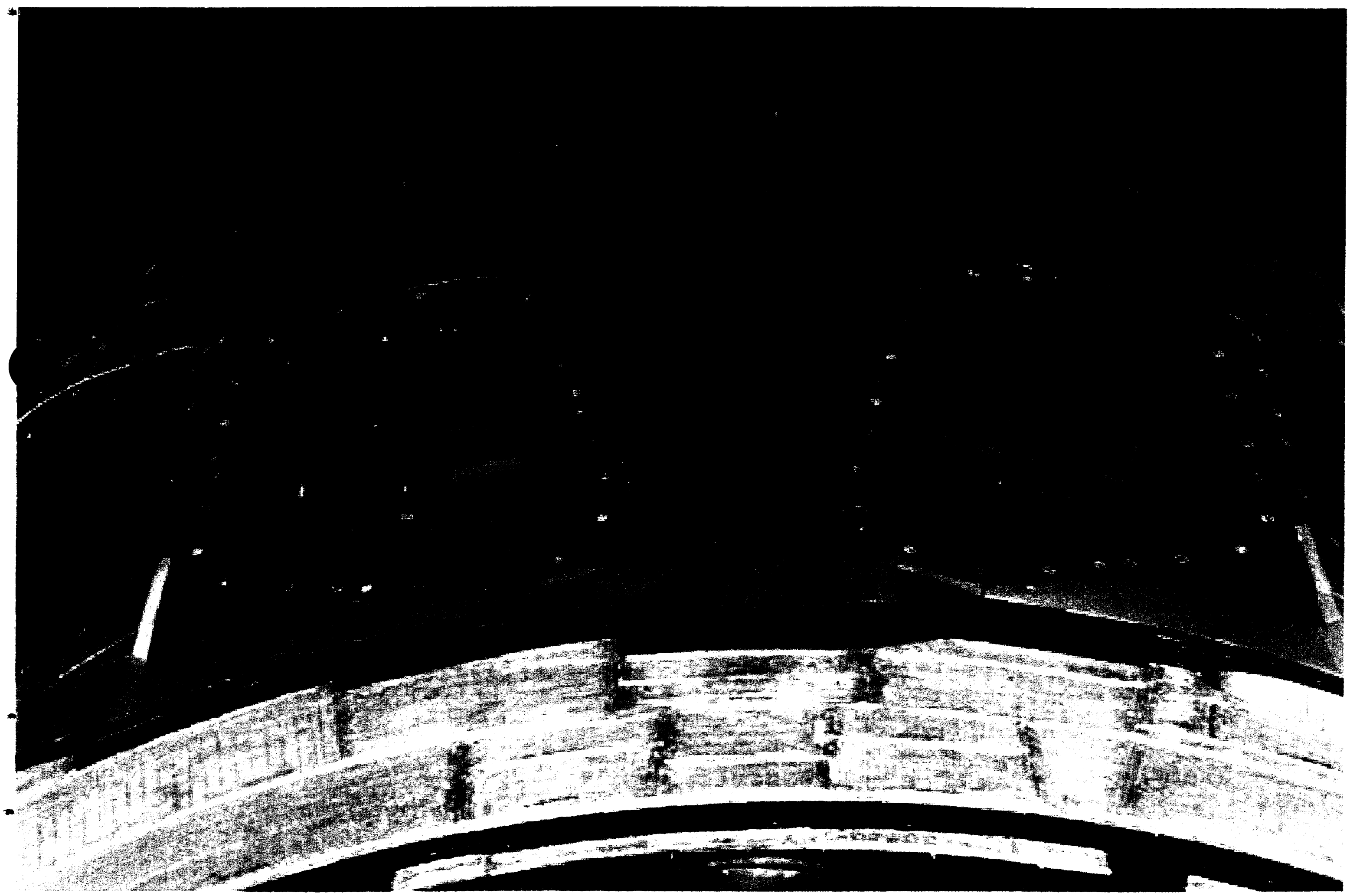
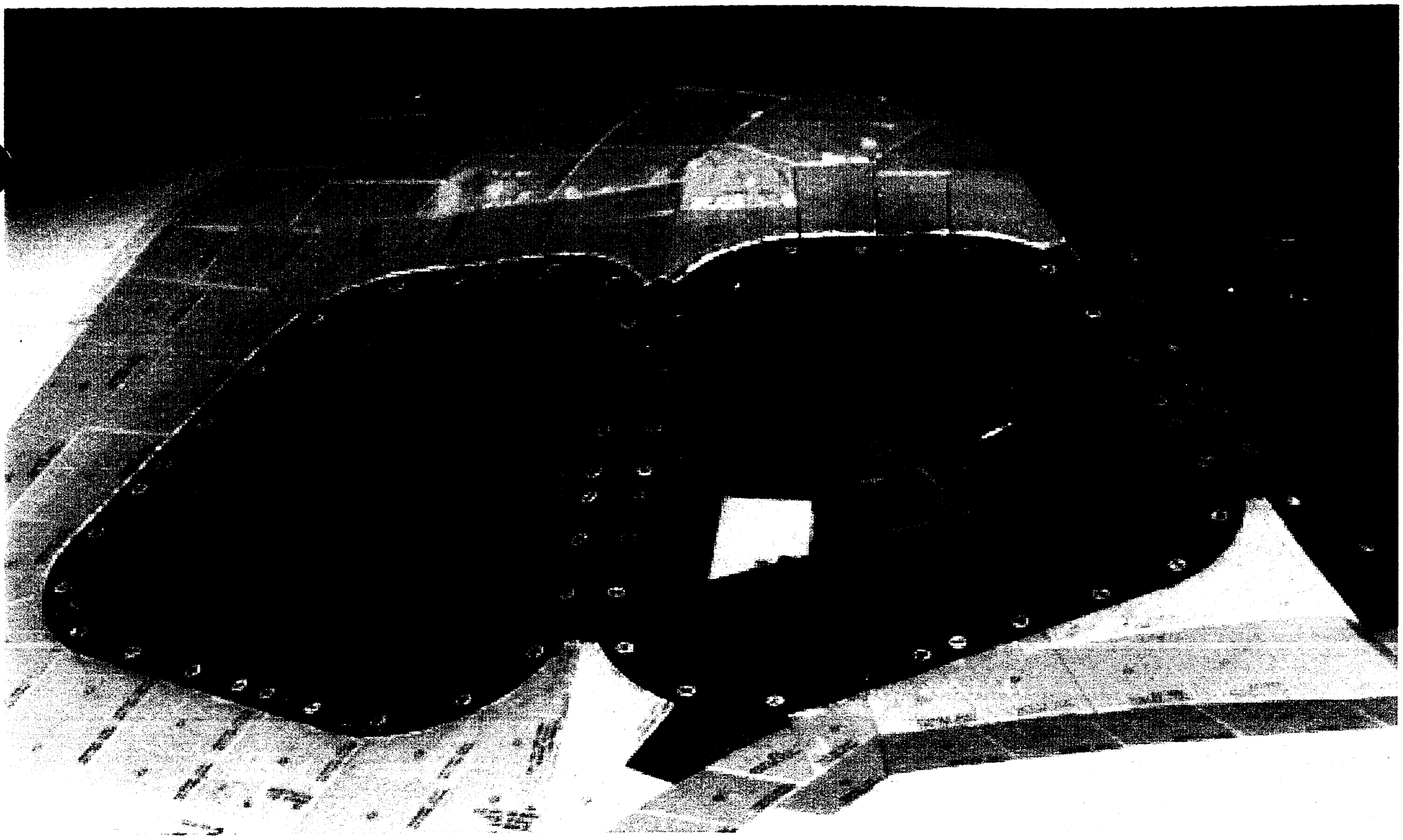


Photo 29: Tiled Area Between Windows

There were 10 hits with two larger than 1-inch in the vicinity of the windows. This damage may be attributed to impacts from FRCS thruster paper covers and the RTV adhesive.



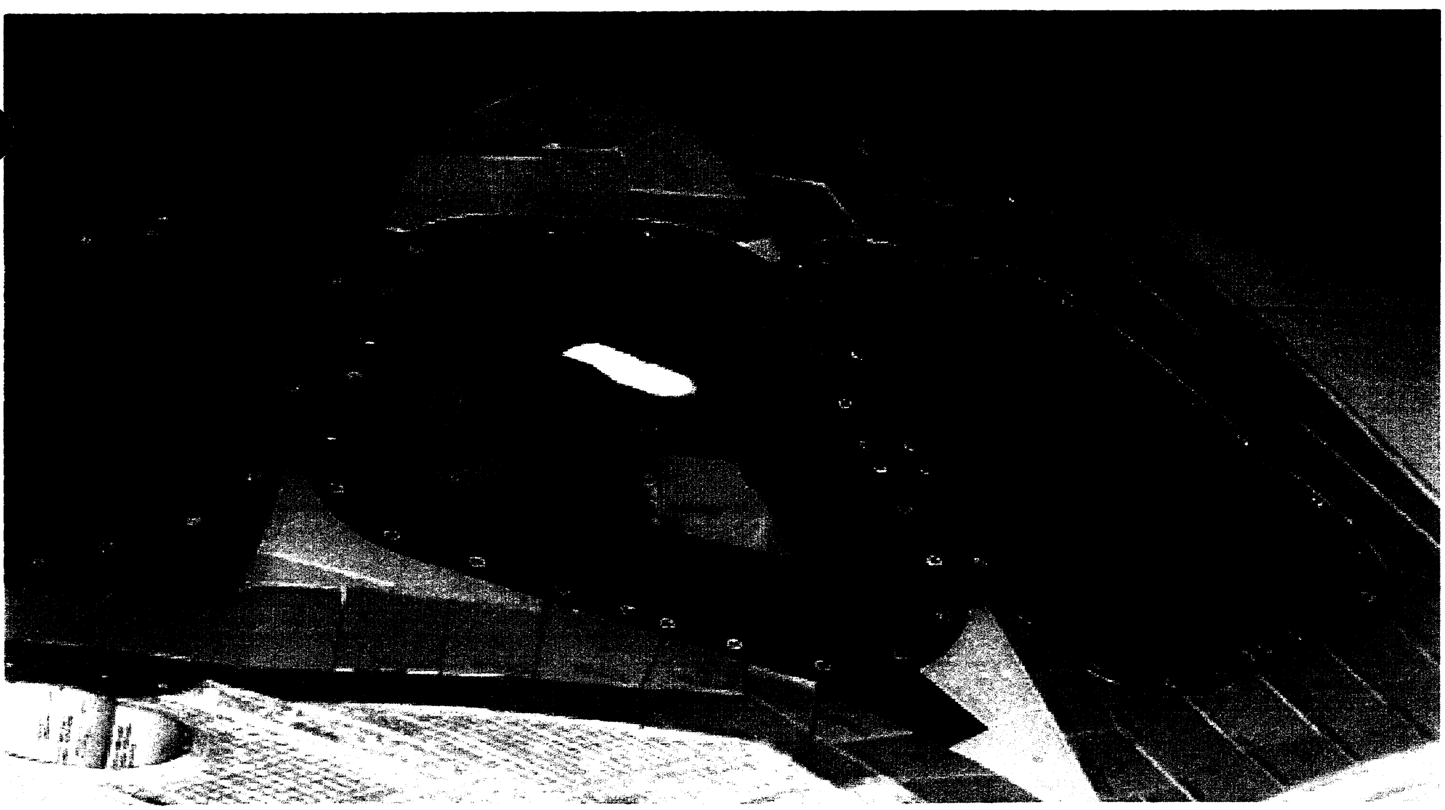


Photo 30: Windows

Damage sites on the window perimeter tiles was less than usual in quantity and size. Hazing and streaking of forward-facing Orbiter windows was moderate. This damage may be attributed to impacts from FRCS thruster paper covers and the RTV adhesive.

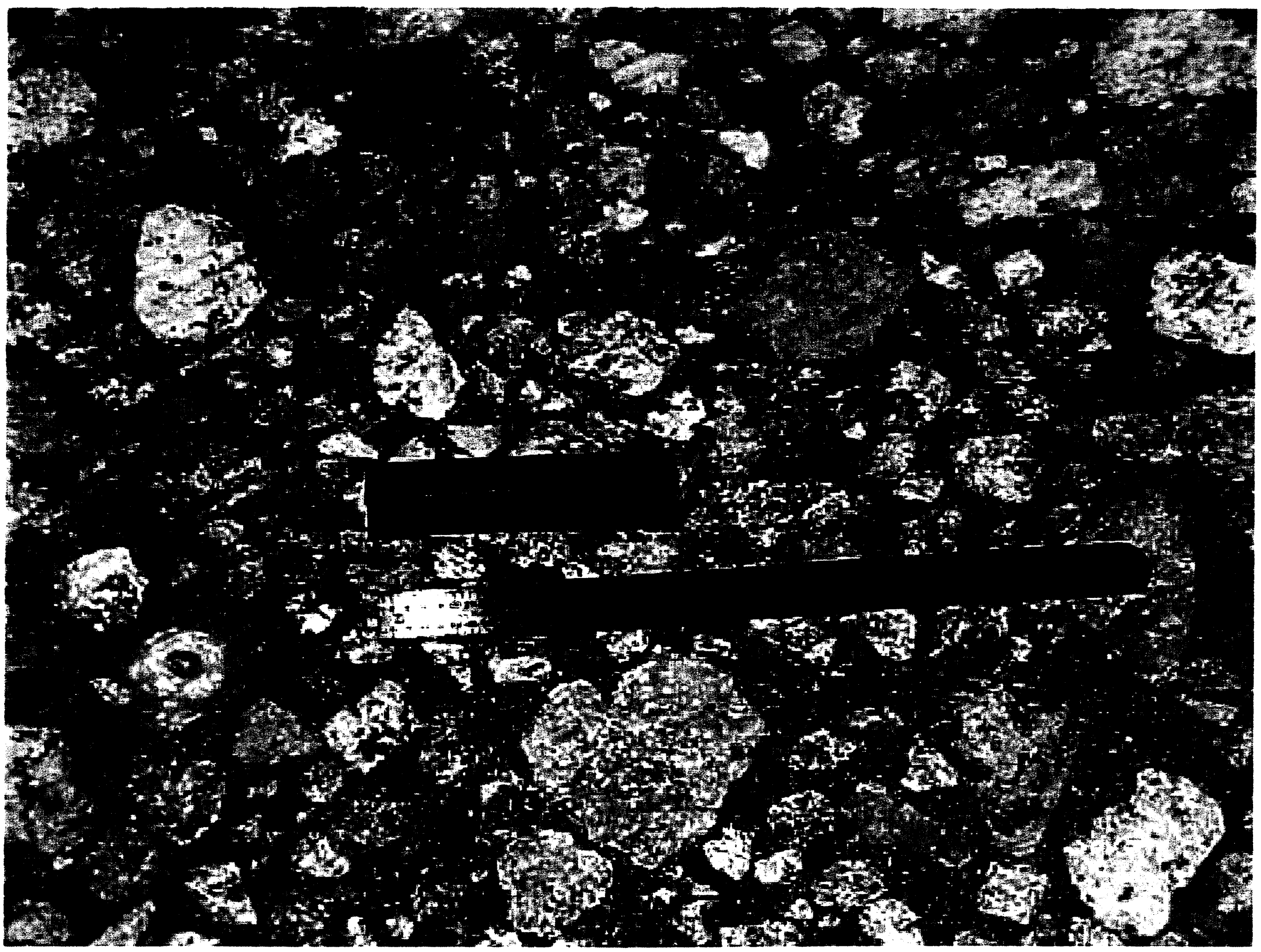


Photo 31: Rudder Seal Found on Runway

A rudder/ speed brake seal metal clip 2.5-inches long by 1-inch wide was recovered 8 feet east of runway centerline at the 3800 foot marker.

APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

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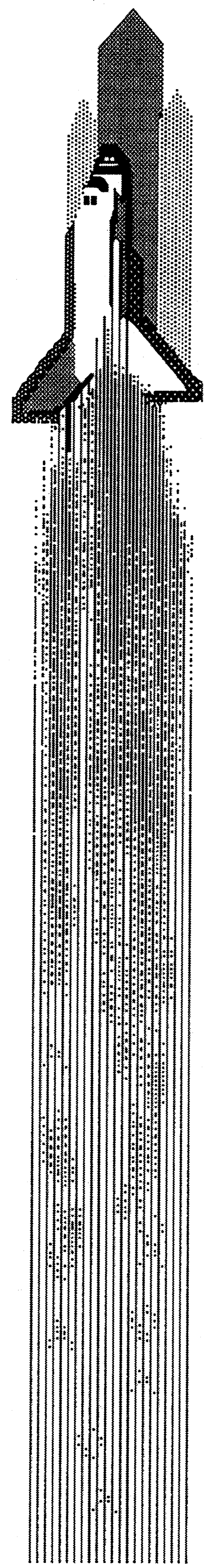

STS-99 Summary of Significant Events

March 22, 2000

image science & analysis group
nasa-jsc

Space Shuttle
STS-99 Summary of Significant Events

Project Work Order - SN3CS

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Table of Contents

Tables and Figures

1. STS-99 (OV-105): FILM/VIDEO SCREENING AND TIMING SUMMARY

1.1 SCREENING ACTIVITIES

1.1.1 Launch

The STS-99 launch of Endeavour (OV-105) from Pad A occurred on Friday, February 11, 2000 at approximately 042:17:43:40.006 UTC as seen on camera E9. SRB separation occurred at approximately 17:45:45.48 UTC as seen on camera ET207A.

No anomalous events were seen.

On launch day, 23 of the 24 expected videos were received and screened. Camera ET213 tracking video was not provided.

Nineteen launch films were screened on February 15, 2000. Camera E76 film was unusable. Twenty-three additional films were received for contingency support and anomaly resolution but were not screened.

Umbilical well cameras flew on OV-105 during STS-99. Photography of the left SRB, the LSRB/ET aft attach, and the External Tank (ET-92) aft dome was acquired using umbilical well camera films during SRB separation. Umbilical well camera photography of the ET was also acquired during ET separation while handheld still photography of the ET was acquired following separation. Handheld video of the ET after separation was not acquired on STS-99.

Video of the External Tank's +Y and –Y thrust panels was not acquired during ascent on STS-99.

1.1.2 On-Orbit

No unplanned on-orbit Shuttle analysis support was requested. Pre-planned real-time analysis support was provided to the Shuttle Radar Topography Mission (SRTM) deploy. Measurements made of the antenna mast's X and Z motion were provided to JPL's Antenna Mechanical Systems (AMS) group during the low and high PRCS jet test firings and the first flycast maneuver. (No post-mission report was requested.)

1.1.3 Landing

Endeavour made an early evening landing on runway 33 at the KSC Shuttle Landing Facility on February 22, 2000 at 23:22:22.5 UTC. Ten videos and ten films were received.

The landing touchdown appeared normal. No anomalous events were seen during the Orbiter approach, landing, and landing roll-out.

Post landing, a sink rate analysis of the STS-99 main landing gear was performed for the main gear touchdown.

The drag chute deploy sequence appeared normal on the landing imagery. Flames from the APU vent located at the forward edge of the base of the vertical stabilizer were seen

during the landing roll out and after wheel stop. Flames from the APU during landing have occurred on previous missions.

According to the pre-mission agreement, the STS-99 landing films were not screened due to budgetary constraints.

1.2 LANDING EVENTS TIMING

The time codes from videos were used to identify specific events during the screening process. The landing event times are provided in Table 1.2.

STS-99 Landing and Drag Chute Event Times from Video

Event	Time (UTC)	Camera
Main gear door opening	053:23:22:01.797	EL17IR
Left main gear inboard tire touchdown	053:23:22:22.495	EL17IR
Right main gear tire touchdown	053:23:22:22.729	EL17IR
Nose gear tire touchdown	053:23:22:33.846	EL17IR
Drag chute initiation	053:23:22:35.727	KTV11L
Pilot chute at full inflation	053:23:22:36.884	KTV11L
Bag release	053:23:22:37.762	KTV11L
Drag chute inflation in reefed configuration	053:23:22:39.764	KTV11L
Drag chute inflation in disreefed configuration	053:23:22:43.234	KTV11L
Drag chute release	053:23:23:04.789	KTV11L
Wheel stop	053:23:23:20.310	KTV15L

Table 1.2 Landing Event Times

2. SUMMARY OF SIGNIFICANT EVENTS

2.1 DEBRIS FROM SSME IGNITION THROUGH LIFTOFF

Multiple pieces of ice debris and vapors were seen falling from the ET/Orbiter umbilicals along the –Z side of the body flap during SSME ignition.

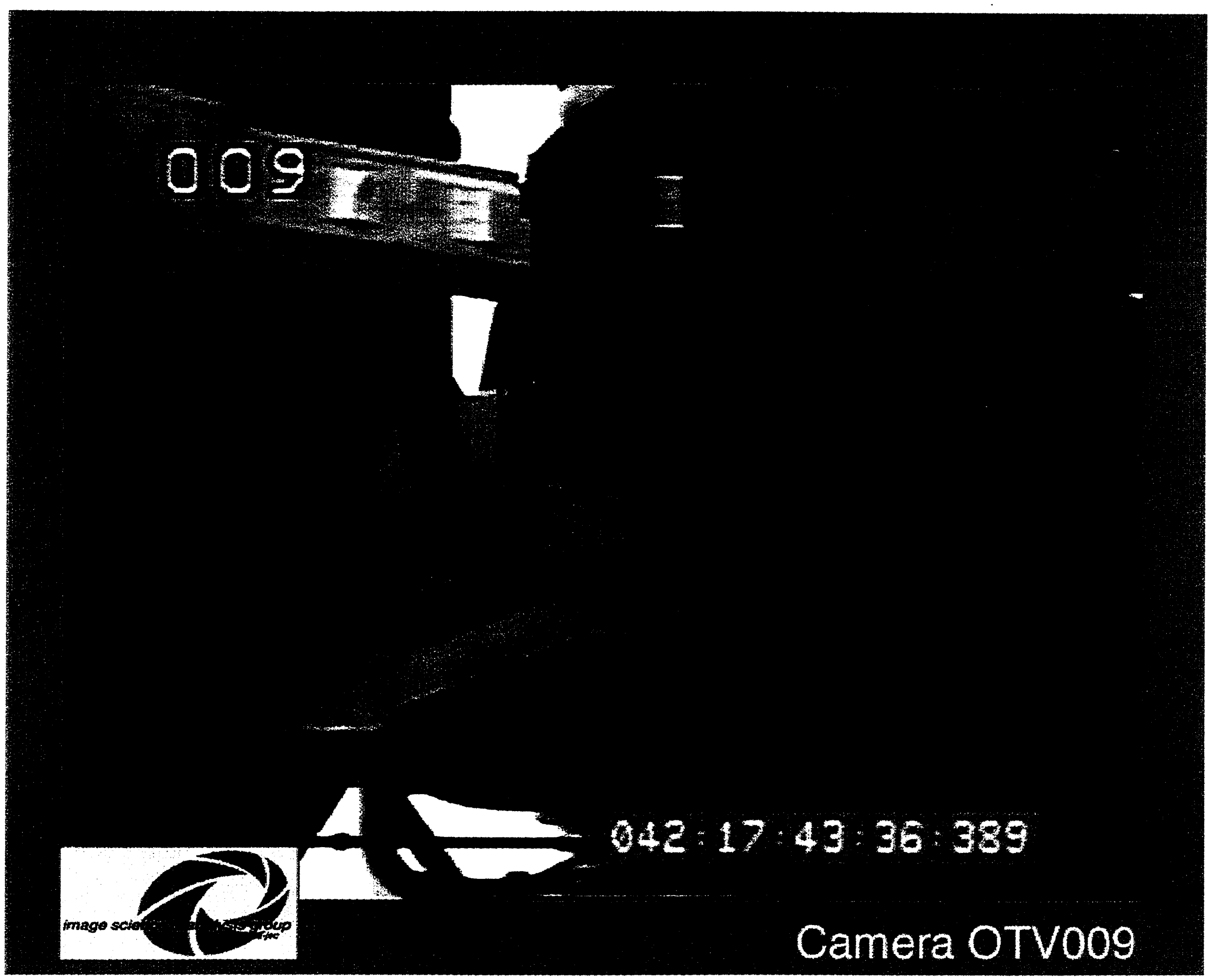


Figure 2.1(A) Ice Debris Contacting Umbilical Well Doorsill

Two pieces of ice debris were seen to contact the LH2 umbilical well doorsill (17:43:35.88, 17:43:36.39 UTC) (Figure 2.1(A). A single piece of umbilical ice debris was seen to contact the body flap (17:43:38.16 UTC). No damage to the launch vehicle was noted. A piece of mylar tape was seen falling from the Orbiter side of the forward end of the LH2 umbilical (17:43:37.341 UTC). (Cameras OTV009, OTV054, OTV61, OTV63, E2, E4, E5, E31, E34, E36)

Small light colored debris (ice/frost) was seen falling from the ET/Orbiter aft attach area at the +Y vertical strut interface with the ET aft dome during SSME ignition

(17:43:35.55 UTC). A single light-colored piece of debris was seen falling past the right outboard elevon (17:43:41.49 UTC). (Camera OTV054)

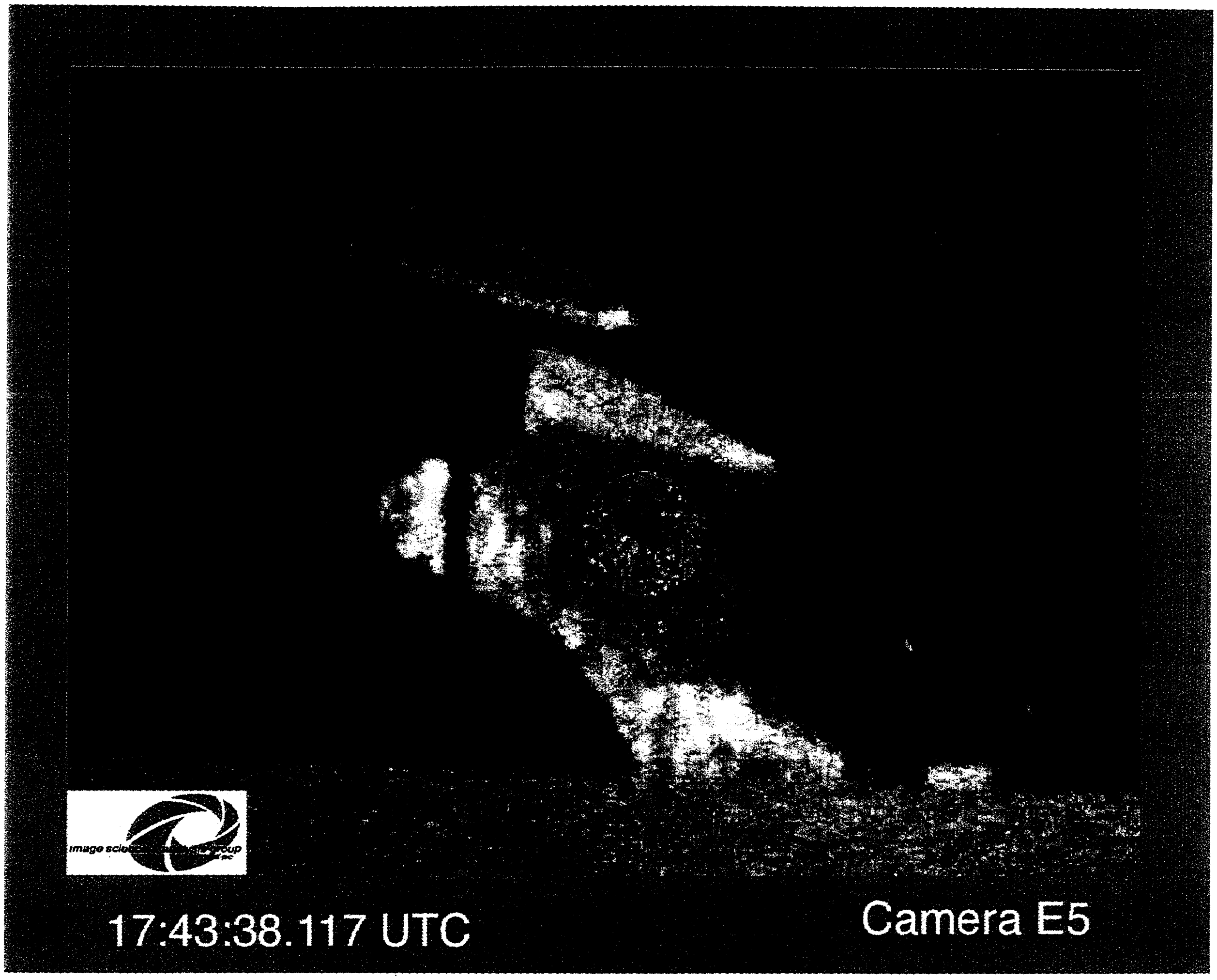


Figure 2.1(B) Unidentified Debris between SSME #2 and SSME #3

An unidentified debris object (possible tile gap filler) was seen falling between SSMEs #2 and #3 on the +Z side of the body flap during main engine ignition (17:43:37.836 UTC). The object was rectangular in shape and was estimated to be approximately 6 x 2 inches in size. It appeared to be light colored on one side and dark on the other. Two additional smaller pieces of debris were seen at approximately the same location just prior to this event (17:43:36.819 and 17:43:37.242 UTC). Two faint orange-colored flashes (possibly debris induced) were seen in the SSME exhaust plumes near the time of this event (SSME #3 at 17:43:37.780 and SSME #2 at 17:43:39.455 UTC). KSC reported that no evidence of a missing tile gap filler from the base heat shield was found during the post landing inspection. (Cameras E5, E15, E20)

Several pieces of light-colored debris (ice/frost) were seen to originate from the forward ET/Orbiter attach bipod area and fall aft between the ET and Orbiter fuselage tiles prior to liftoff (17:43:37.437 UTC). (Camera E36)

A single piece of light-colored debris (ice/frost) was seen to fall aft from the area of +Y ET/Orbiter aft attach brace (just below the ET +Y longeron) during SSME ignition (17:43:35.547 UTC). (Camera E5)

Typical of previous missions, a small amount of ice debris was seen falling aft along the External Tank during the retraction of the GH2 vent arm. (Camera E34)

2.2 DEBRIS DURING ASCENT

An elongated, flexible piece of sound suppression water baffle material was seen in the vicinity of the LO2 TSM and the base of the RSRB during liftoff (17:43:42.605 UTC). (Cameras E2, E5)

Debris typical of that seen on previous missions were seen aft of the launch vehicle during ascent. Pieces of ET/Orbiter umbilical ice debris were seen aft of the body flap (examples - 17:43:52.5, 17:43:46.9 UTC). RCS paper debris was seen near the SSME rims, near the vertical stabilizer (example - 17:43:58.4 UTC), and aft of the vehicle from liftoff through the roll maneuver, and beyond (examples – 17:43:46.9, 17:43:48.8, 17:43:58.1, 17:44:04.9, 17:44:10.7 UTC). A small light-colored piece of debris from an undetermined origin was seen on the –Z side of the vehicle between the two SRBs near the ET aft dome at 17:43:48.651 UTC. A single light-colored piece of debris (probably umbilical purge barrier material) was seen near the trailing edge of the body flap before falling aft into the SSME exhaust plume (17:43:59.95 UTC). (Cameras E52, E54, E63, E207, E212, E222, E223, E224)

A single, large, unidentified debris object was seen just aft of the Orbiter during ascent (17:44:40.99 UTC). A second large, light-colored piece of debris was also seen near the body flap during ascent (17:44:36.38 UTC). (Camera ET207A)

2.3 MOBILE LAUNCH PLATFORM (MLP) EVENTS

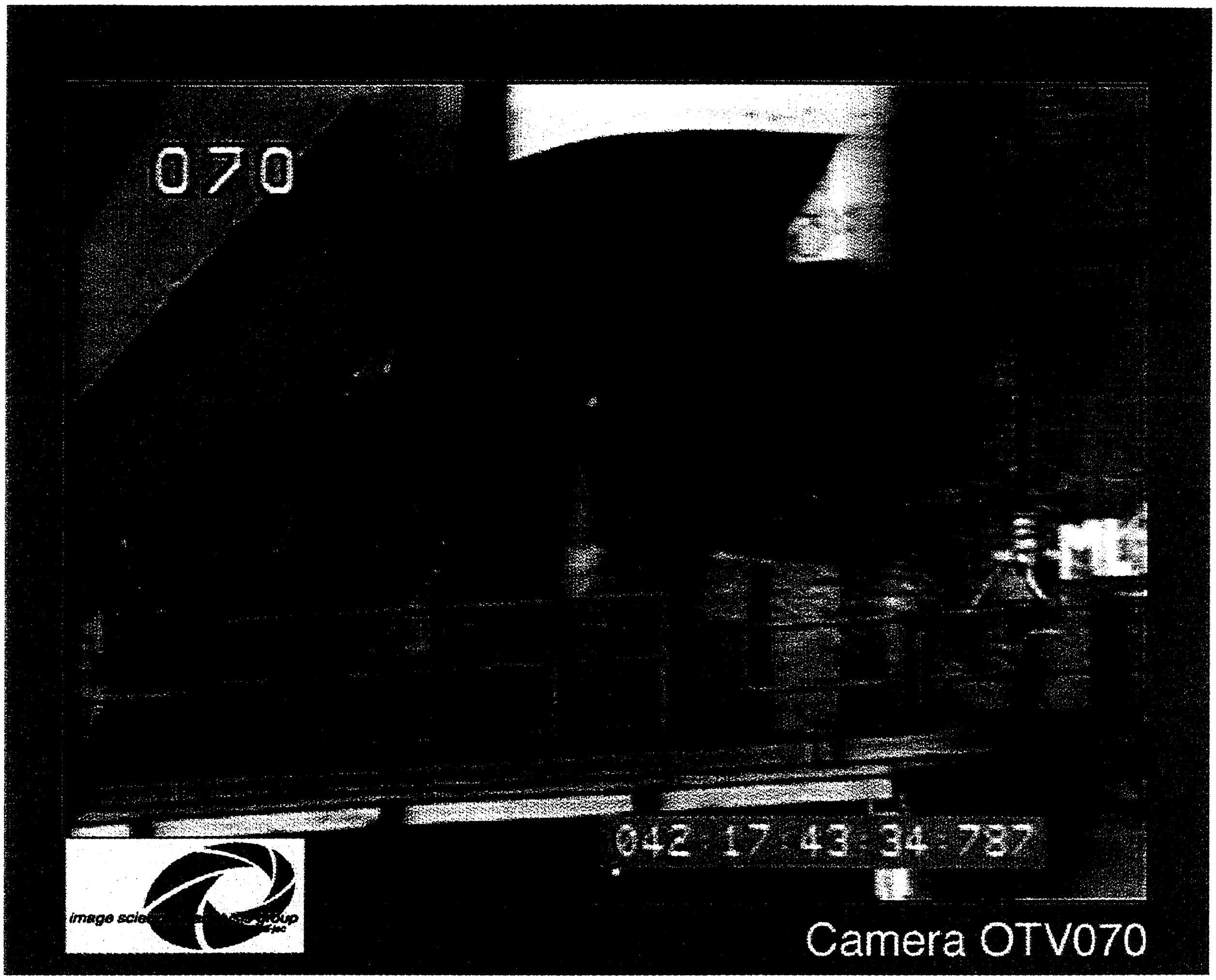


Figure 2.3(A) Orange Vapor Seen During SSME Ignition

Orange vapor (possibly free burning hydrogen) was seen forward of the SSME rims during SSME ignition (17:43:34.79 UTC). Orange vapor forward of the SSME rims has been seen on previous mission films and videos. (Cameras OTV063, OTV070, E2, E5, E19, E20)

Vapor from an ET vent louver was seen prior to and at liftoff. (Camera OTV060)

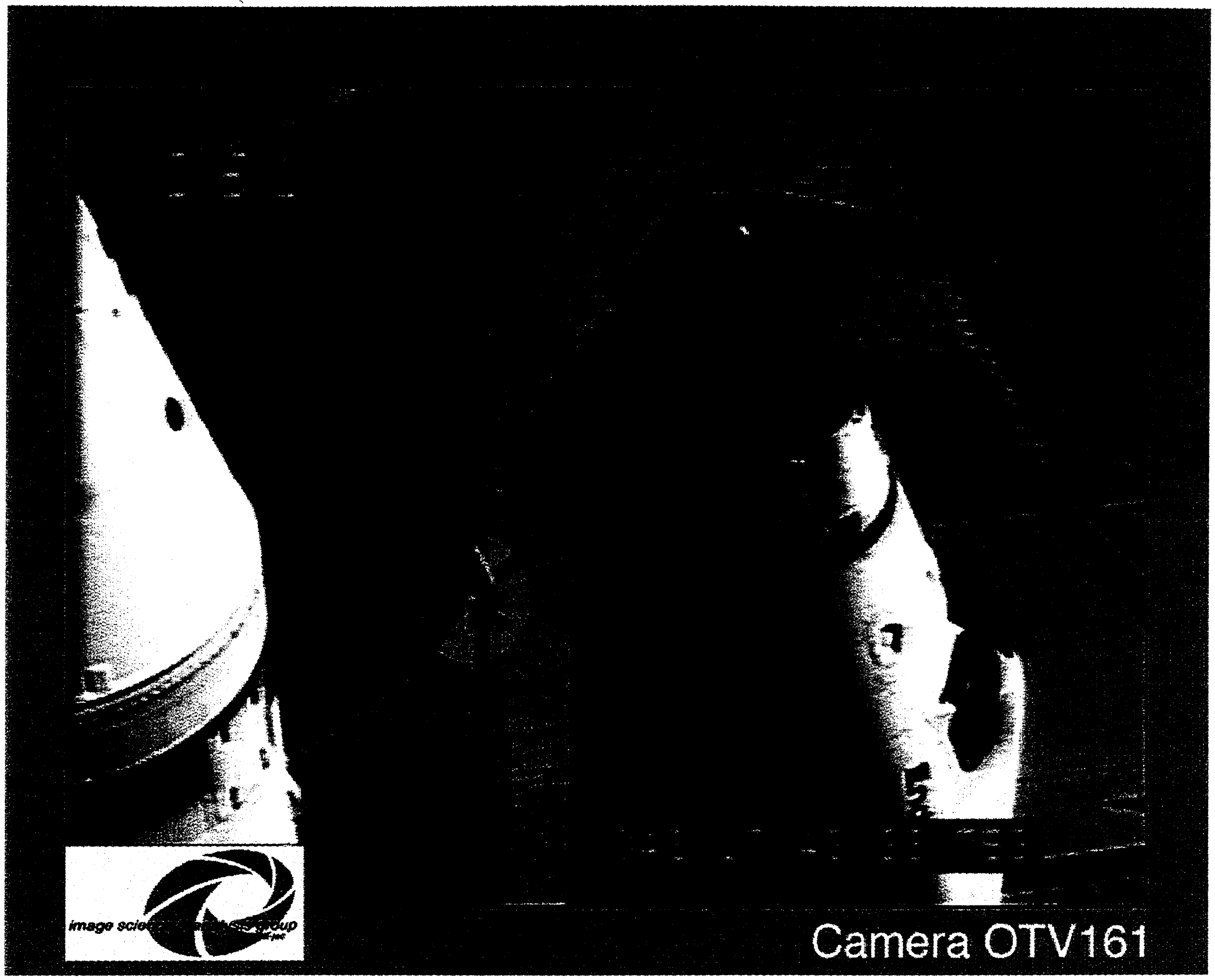


Figure 2.3(B) Vapor Near Left Foot of ET/Orbiter Forward Bipod

A faint, white-colored vapor (reported as a thermal short by KSC) was seen at the left foot of the ET/Orbiter forward bipod prior to liftoff (17:43:33.75 UTC). (Camera OTV061)

The SSME ignition appeared normal on the high-speed engineering films. The SSME Mach diamonds appeared to form in the expected sequence (3, 2, 1). The times for the Mach diamond formation given in Table 2.3 are from camera film E19.

SSME	TIME (UTC)
SSME #3	17:43:36.691 UTC
SSME #2	17:43:36.865 UTC
SSME #1	17:43:37.148 UTC

Table 2.3 SSME Mach Diamond Formation Times

Small areas of tile surface coating material erosion were seen during SSME ignition on the base of the right RCS stinger (17:43:35.775 UTC), the base of the left RCS stinger (17:43:36.622 UTC), and at the base of SSME #2 (17:43:41.463 UTC). (Cameras E18, E19, E20)

Four faint orange-colored flashes were seen extending aft from the SSME #1 nozzle rim prior to liftoff (17:43:37.148, 17:43:38.370, 17:43:38.638, and 17:43:39.055 UTC). (Camera E19)

No indication of holddown post (HDP) stud hang-ups were seen. No debris was seen falling from the HDP stud holes. PIC firing was timed at 17:43:40.006 UTC on HDP M-1 camera film E9.

2.4 ASCENT EVENTS

White-colored vapor (probably water) was seen streaming from the drain hole at the mid-level of the trailing edge of the rudder speed brake during liftoff and early ascent (17:43:46.981 UTC). This event has been seen on previous missions. (Camera E52)

Multiple orange-colored flares (probably debris induced) were seen in the SSME exhaust plume during ascent (17:43:46.981, 17:44:06.025, 17:44:13.425, 17:44:13.976, 17:44:16.193, and 17:44:23.862 UTC). (Cameras E52, E207, E222, E223, E224, ET207A, ET212A)

Body flap motion was seen during ascent. The amplitude and frequency of the body flap motion appeared similar to that seen on previous mission imagery. No follow-up action was requested. (Camera E207)

2.5 ONBOARD PHOTOGRAPHY OF THE EXTERNAL TANK (ET-92)

2.5.1 Analysis of the Umbilical Well Camera Films

ET-92 was the light weight (LWT) configuration rather than the super light weight tank (SLWT) flown since STS-91. KSC reported that because of the LWT configuration, no venting was done on the +Z intertank stringer TPS. Venting was only done to the +Z side of the thrust panels.

Three umbilical well cameras (one 35mm and two 16mm cameras) flew on OV-105 during STS-99. The +X translation maneuver was performed on STS-99 to facilitate the imaging of the ET with the umbilical well cameras.

16mm Umbilical Well Camera Films

The film quality of both 16mm umbilical well films is very good. However, backlighting by the late afternoon Sun of the LSRB and the ET hindered the film analysis through ET separation. Timing data was present on the wide-angle (5mm-lens) 16mm umbilical well camera film (FL101). The expected timing data was not present on the normal angle (10mm lens) 16-mm umbilical well camera film (FL102).

The LSRB separation appeared normal on the 16mm umbilical well camera films. Numerous light-colored pieces of debris (insulation), and dark debris (charred insulation) were seen throughout the SRB separation film sequence. Typical ablation and charring of the ET/Orbiter LH2 umbilical electric cable tray and the aft surface of the -Y upper strut fairing were seen prior to SRB separation. Numerous irregularly shaped pieces of debris (charred insulation) were noted near the base of the LSRB electric cable tray prior to SRB separation. Pieces of TPS were seen detaching from the aft surface of the horizontal section of the -Y ET vertical strut. Several small pieces of dark-colored debris were seen near the aft LSRB/ET attach at SRB separation. There was less blistering of the fire barrier material on the outboard side of the LH2 umbilical than typically seen. The amount of ablation of the TPS on the aft dome was typical of previous flights. No anomalies were seen on the left and right SRB nose caps during SRB separation.

Figure 2.5.1(A) Umbilical Purge Barrier Tape Debris

Umbilical purge barrier tape was seen falling aft from behind (-Z side) the LH2 umbilical prior to ET separation (Figure 2.5.1(A).

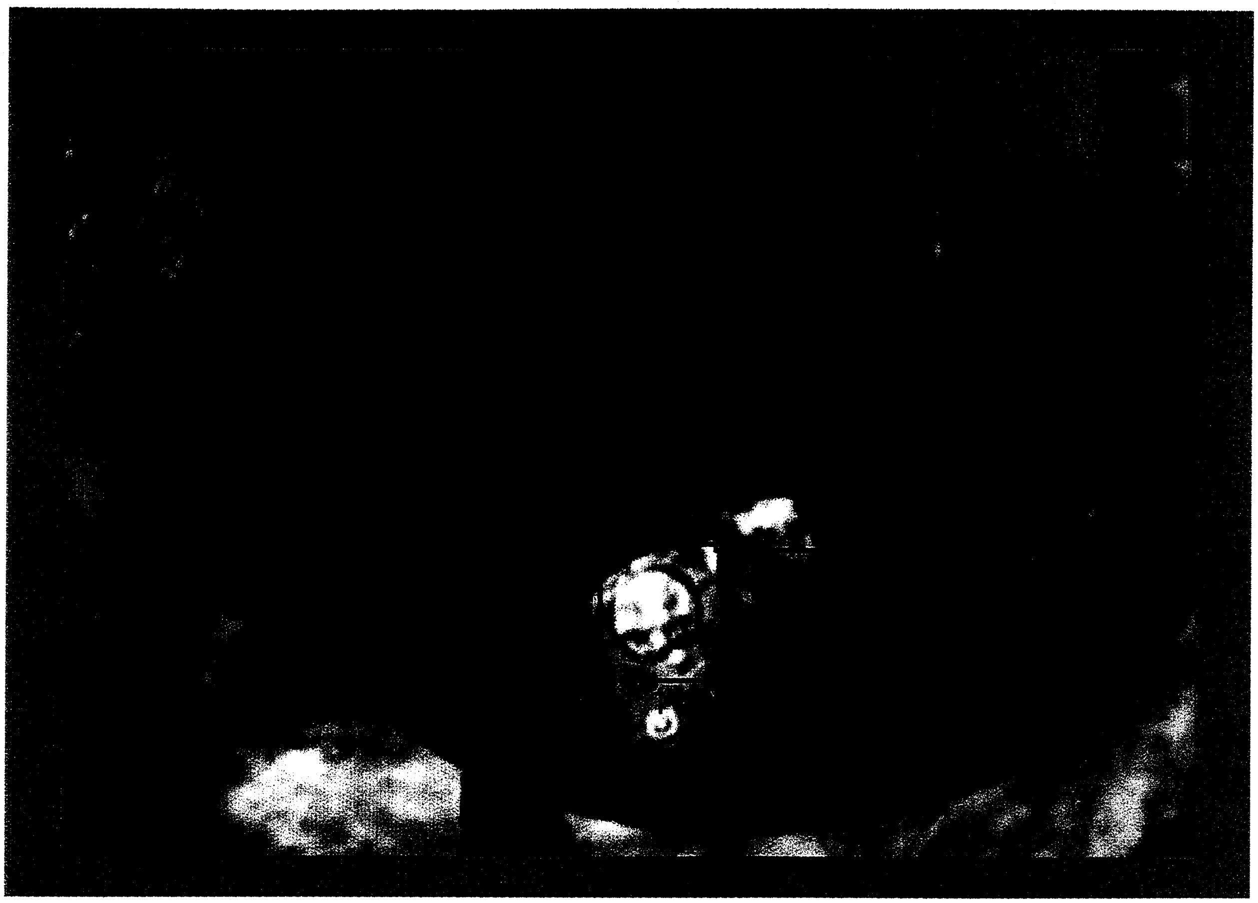


Figure 2.5.1(B) LH2 Umbilical View

The ET separation from the Orbiter appeared normal. Typical vapor and multiple light-colored pieces of debris were seen after the umbilical separation. No anomalies were noted on the face of the LH2 umbilical after ET separation. As typically seen on previous missions, frozen hydrogen was visible on the orifice of the LH2 17 inch connect (Figure 2.5.1(B), annotation 1). The ice/frost visible above the LH2 umbilical (aft of the -Y end of the ET cross beam) has been seen on previous missions (Figure 2.5.1(B), annotation 2). The red-colored purge seal on the EO-2 ball joint fitting appeared to be in place (Figure 2.5.1(B), annotation 3). The small erosion marks typically seen on the -Y thrust strut were not seen on this flight imagery. The -Y ET thrust panel was in shadow, therefore, was too dark for analysis. No anomalous conditions were noted on the ET on the 16mm films other than those also seen on the higher resolution 35mm umbilical well film (see 35mm Umbilical Well Camera Film section below).

<u>35mm Umbilical Well Camera Film</u>

The 35mm Umbilical Well camera film quality is excellent. The lighting on the ET is excellent with very little shadowing.

Overall, the ET appeared to have been in good condition after separation from the Orbiter based on the screening on the close-up 35mm umbilical well camera film.

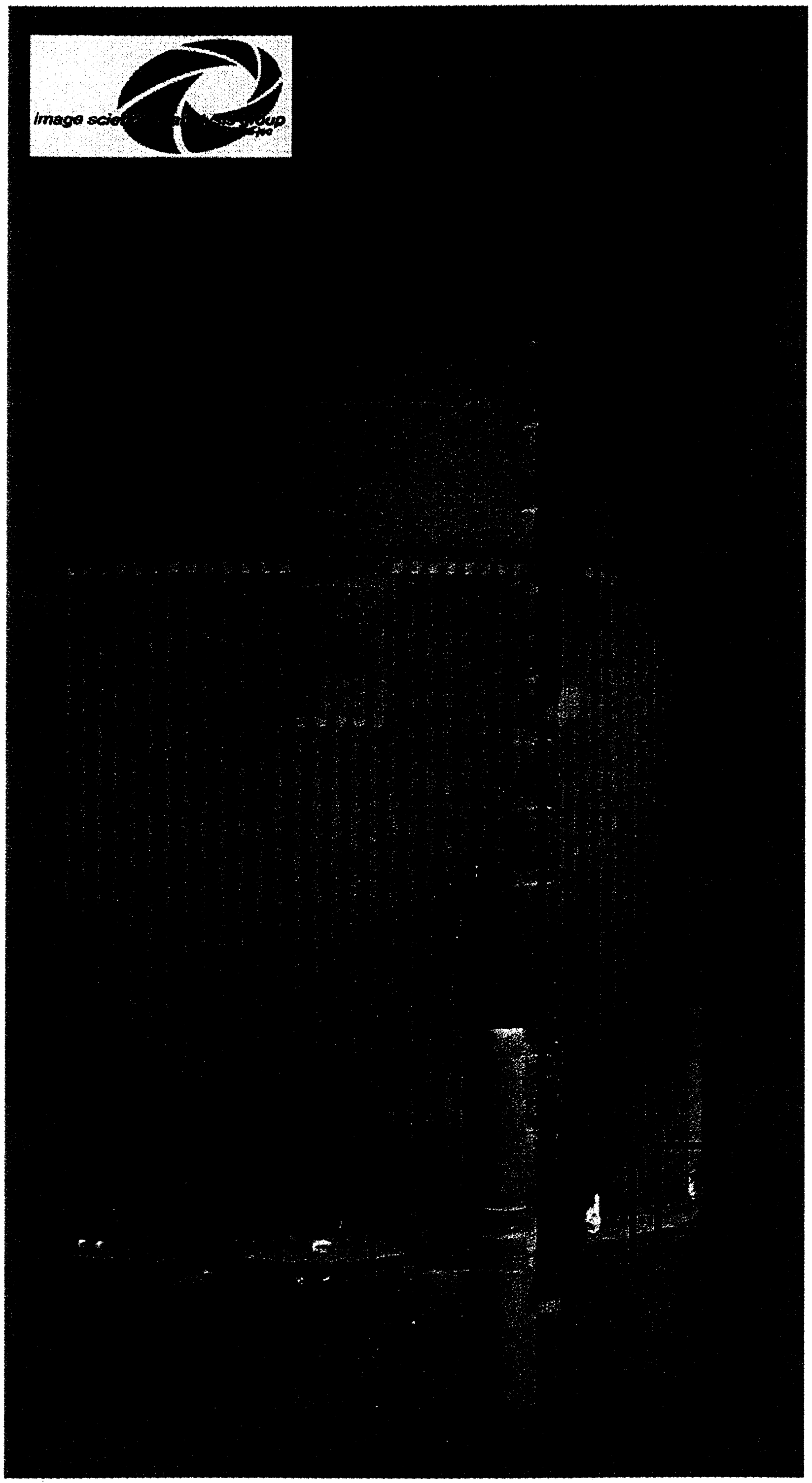


Figure 2.5.1(C) ET +Z Intertank View

The LH2 tank and the LO2 tank/Ojive TPS appeared to be in excellent condition. The nose of the ET appeared free of damage and the nose cap appeared in good condition. The +Z ET nose just aft of the ET nose cone did not appear to have the gray-colored band of pock marks (possible missing TPS) seen on STS-90, STS-91, STS-95, and other previous missions (discoloration in this area was thought to have been due to aero friction and heating). The RSRB separation motor burn scar appeared typical of previous missions (Figure 2.5.1(C), annotation 1). No divots were seen in this burn scar.

Two small white-colored divots (approximately 6 x 4 inches in size) are visible on the LH2 tank-to-intertank flange closeout in the –Y direction from the -Y foot of the forward bipod (Figure 2.5.1(C), annotation 2). One large, white-colored divot (approximately 7 x 4 inches in size) is visible on the LH2 tank-to-intertank flange closeout between the legs of the forward ET/Orbiter attach bipod (Figure 2.5.1(C), annotation 3). The dark area in the center of this divot may be exposed substrate. One large, white-colored divot (approximately 15 x 8 inches in size) located in the +Y direction from the LO2 feedline is visible on the ET intertank acreage and extends aft into the LH2 tank-to-intertank flange closeout (Figure 2.5.1(C), annotation 4). One large, white-colored divot or area of TPS erosion (approximately 15 inches in length) is visible at the aft –Y corner of the ET +Y Thrust Panel (Figure 2.5.1(C), annotation 5). Divots on or near the LH2 tank-to-intertank closeout flange have been typically seen on previous mission films.

Two small divots (approximately 1 to 1.5 inches in size) are visible just forward of the LO2 forward feedline bellows on an intertank stringer head.

Three small (one inch in size) divots appear to be present on an intertank stringer head located on the +Y side of the forward end of the LO2 feedline.

TPS erosion was noted on a bracket over the LH2 press line (5th bracket forward from the crossbeam).

The visible portion of the +Y ET Thrust Panel appears in excellent condition on the 35mm umbilical well film. No divots were noted on the +Y ET thrust panel TPS. As expected, the left (-Y) SRB thrust panel was not imaged on this film.

The bipod jack pad closeouts appear intact. One divot was seen on an intertank stringer head just forward of the flange closeout under the forward bipod. Other than this divot, the small, randomly located, divots normally seen on the intertank stringer heads forward of the bipod were not detected on the STS-99 (ET-92) tank. Several very small, shallow, "popcorn" divots are visible on the LH2 tank acreage just aft of the bipod.

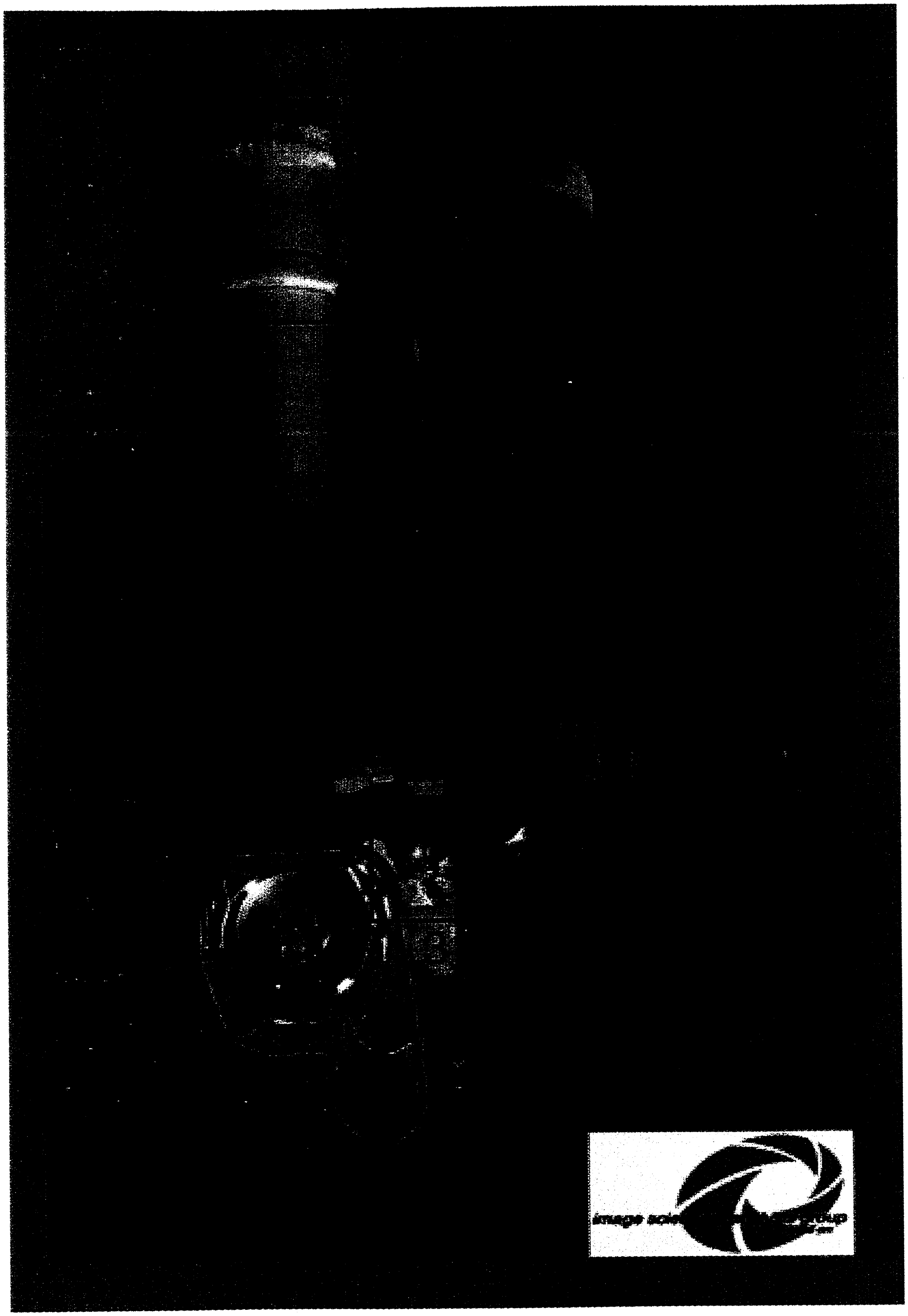


Figure 2.5.1(D) LO2 Umbilical View

Minor TPS chipping and very small divots (typical of previous missions) were seen on the aft LO2 feedline flange. The white-colored area on the LO2 feedline bellows located aft of this flange was ice that was carried into orbit. (Figure 2.5.1(D), annotation 1). Small, shallow areas of TPS erosion and divoting are visible on the forward flange of the +Y ET/Orbiter thrust strut. A large area (approximately 10 x 10 inches in size) of TPS erosion is visible on the +Y ET/Orbiter thrust strut TPS (Figure 2.5.1(D), annotation 2). Ablation and divoting of the TPS on the vertical section of the +Y electric cable tray adjacent to the LO2 umbilical is visible (Figure 2.5.1(D), annotation 3). Multiple (but insignificant appearing), shallow "popcorn" divots are visible on the aft LH2 tank TPS (to the left of the LO2 feedline and forward of the crossbeam). Popcorn divots in this location were typically seen on previous mission films. The shallow, "popcorn" divots visible on the ET aft dome appear to be less than typically seen on previous mission films.

The face of the LO2 umbilical carrier plate appeared to be in excellent condition (the lightning contact strips appeared to be in place).

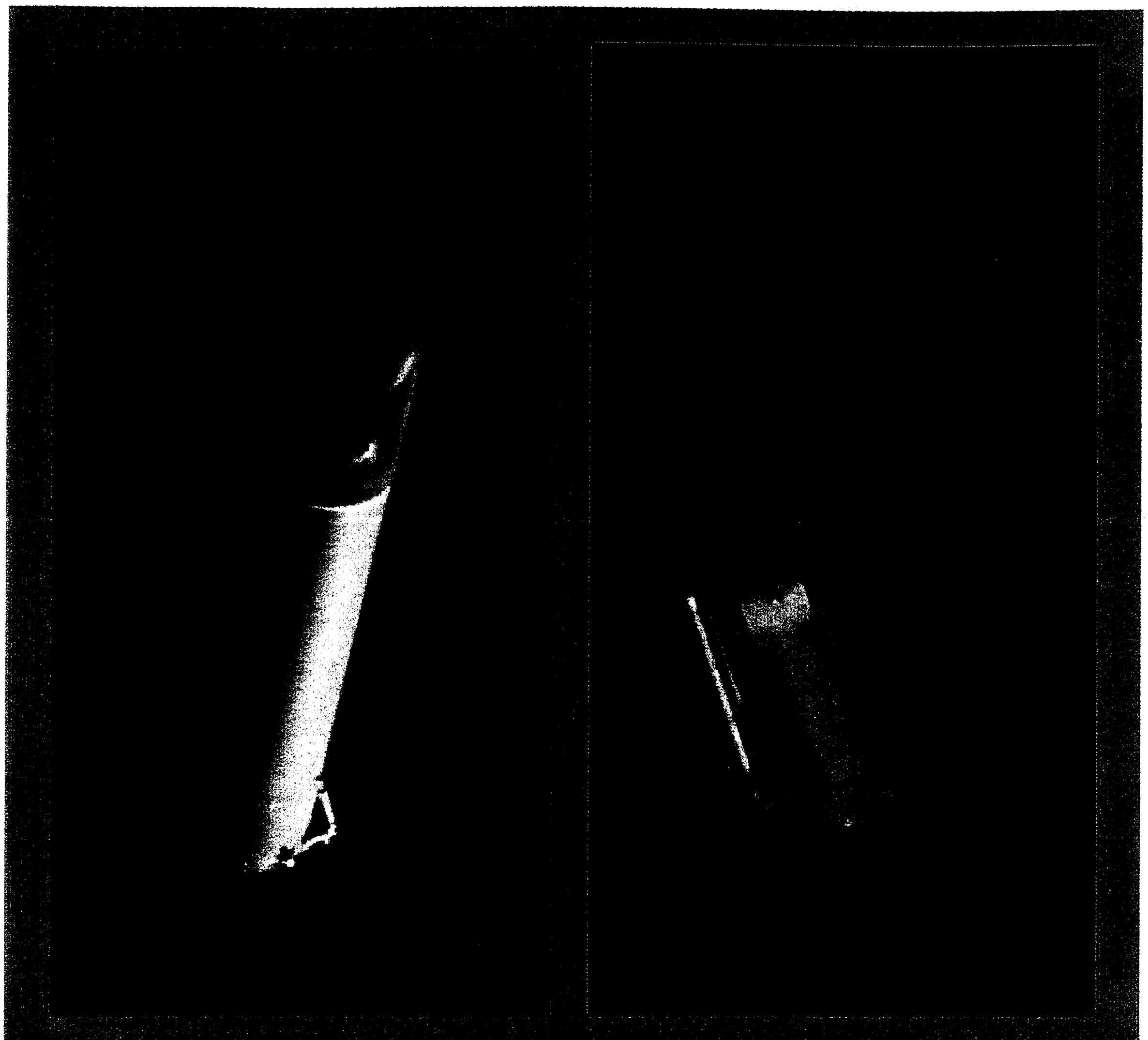
The portion of the red-colored purge seal (not in shadow) on the EO-3 ball joint fitting appeared to be in place (Figure 2.5.1(D), annotation 4).

2.5.2 ET Handheld Photography

The STS-99 handheld pictures of the External Tank (ET-92) are of excellent quality. However shadows from the late afternoon soon hindered the analysis of many of the views. Timing data is present on the film. The first picture was taken at 18:44 (minutes:seconds) MET. The distance of the ET from the Orbiter was calculated to be approximately 2.1 km on the first photographic frame acquired. The separation velocity of the ET from the Orbiter was estimated to be ~5.8 m/sec.

The astronauts performed a manual pitch maneuver from the heads-up position to bring the ET into view in the Orbiter overhead windows for the handheld photography. (STS-99 was the ninth flight using the roll-to-heads-up maneuver).

Thirty-five images of the ET were acquired using the handheld 35mm Nikon camera with a 400mm lens (roll 309). Views of the nose, aft dome and all sides of the ET were obtained. The normal SRB separation burn scars and aero-heating marks were noted on the intertank and nose TPS of the ET.



-Y Thrust Panel +Y Thrust Panel

Figure 2.5.2 Handheld ET Views

If present, divots greater than eight inches in size should have been detectable on the surface of the ET including the ET thrust panels. However, only one possible divot in addition to those seen on the higher resolution umbilical well films was noted during the screening. This divot was located on the LH2 tank-to-intertank closeout flange on the –Z (far) side of the ET (frame 14).

Venting from the region of –Y axis of the ET intertank was seen on ten of the handheld camera views (Figure 2.5.2, +Y Thrust Panel view).

Table 2.5.2 contains the frame numbers and the time that the ET venting was seen on the handheld camera views.

FRAME	TIME (MIN:SECONDS MET)
13	21:14
14	21:16
15	21:20
16	21:29
17	21:31
22	22:05
26	22:19
27	22:22
28	22:26
29	22:31

Table 2.5.2 Frame Number and Time ET Venting is Visible

Venting from the ET intertank region has been seen on five (recently flown) previous missions (STS-87, STS-89, STS-90, STS-91, STS-95).

2.5.3 ET Handheld Video

The crew handheld video of the ET was not acquired on STS-99.

2.6 ET THRUST PANEL VIDEO

The SRB video cameras that view the ET thrust panels were not flown on STS-99.

2.7 LANDING SINK RATE ANALYSIS

Image data from the centerline video camera at the approach end of runway 33 was used to determine the landing sink rate of the main gear. In the analysis, data from approximately one second of imagery immediately prior to touchdown was considered. Data points defining the main gear struts were collected on every frame (31 frames of the data during the last second prior to touch down). An assumption was made that the line of sight of the camera was perpendicular to the Orbiter's y-axis. The distance between the main gear struts was used as a scaling factor. The main gear height above the runway was calculated by the vertical difference between the main gear struts and a reference point on the runway. A trendline was determined considering the height of the Orbiter above ground with respect to time. The sink rate equals the slope of this regression line.

The left main gear sink rate for STS-99 landing at one second, at half a second, and at a one quarter of a second are provided in Table 2.7. A plot describing these sinkrates is shown in Figure 2.7. Due to the early evening landing and the resulting dark images, the

2.8 OTHER

2.8.1 Normal Events

- elevon motion prior to liftoff
- RCS paper debris from SSME ignition through liftoff
- ET twang
- ice and vapor from the LO2 and LH2 TSM T-0 umbilical prior to and after disconnect
- multiple pieces of ET/Orbiter umbilical ice debris falling along the body flap during liftoff
- vapor off the SRB stiffener rings
- acoustic waves in the exhaust cloud during liftoff
- debris in the exhaust cloud after liftoff
- expansion waves after liftoff
- charring of the ET aft dome
- ET aft dome outgassing
- roll maneuver
- condensation around the launch vehicle
- linear optical effects
- recirculation
- SRB plume brightening
- SRB slag debris before, during, and after SRB separation

2.8.2 Normal Pad Events

Normal pad events observed included:

- hydrogen burn ignitor operation
- FSS and MLP deluge water activation
- sound suppression system water operation
- GH2 vent arm retraction
- TSM T-0 umbilical operations
- LH2 and LO2 TSM door closures

degraded resolution of video compared to film, and camera motion, the sink rate estimates for STS-99 are not as accurate as typical previous missions.

Time Prior to Touchdown	Left Main Gear Sink Rate	Estimated Error (1σ)
1.00 Sec.	1.1 ft/sec	± 0.1 ft/sec
0.50 Sec.	1.6 ft/sec	± 0.2 ft/sec
0.25 Sec.	1.5 ft/sec	± 0.4 ft/sec

Left Main Gear Touchdown = 053:23:22:22.495 (UTC)

Table 2.7 Main Gear Landing Sink Rate

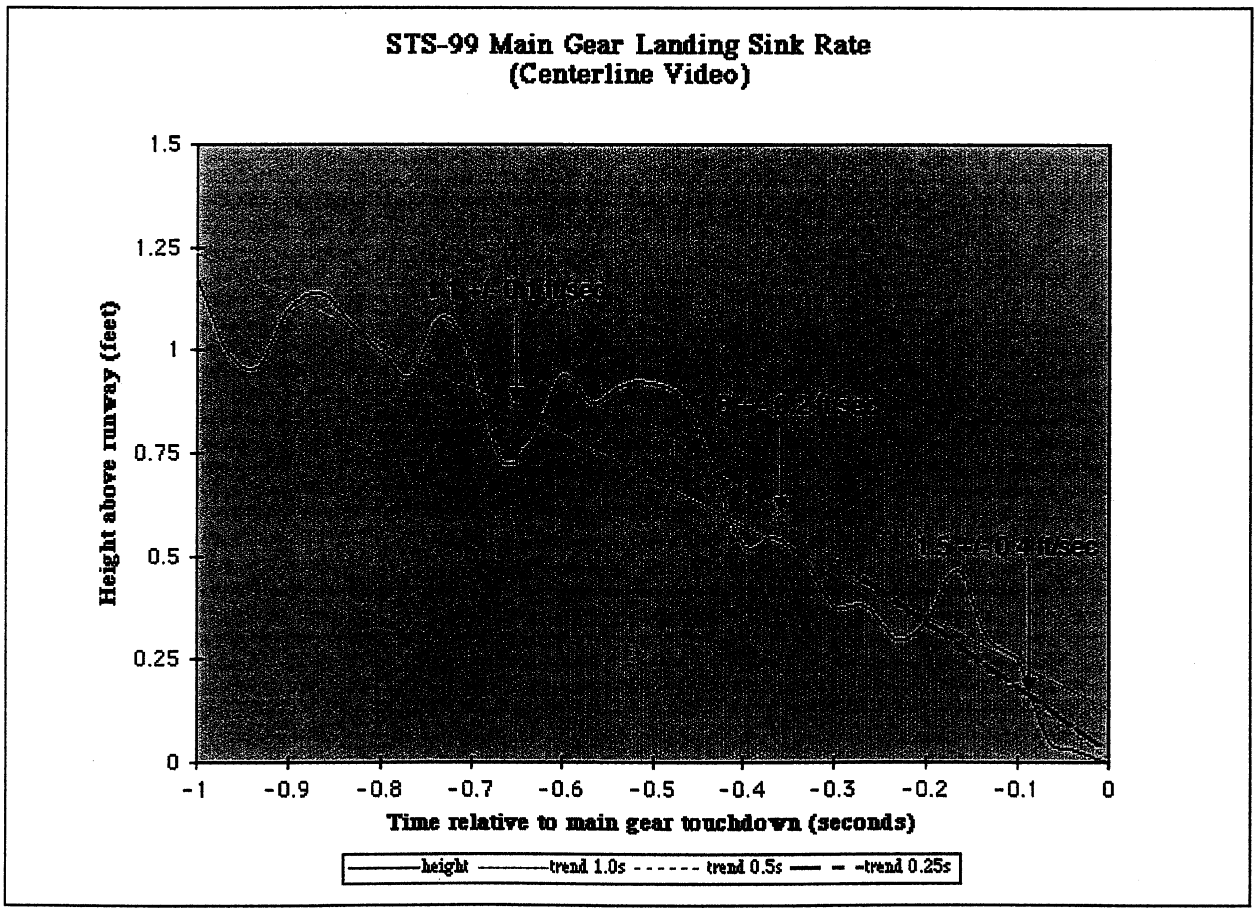


Figure 2.7 Main Gear Landing Sink Rate

APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY

Space Shuttle Mission STS-99

Engineering Photographic Analysis Summary Report
Marshall Space Flight Center

Prepared: March 14, 2000

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STS-99

Engineering Photographic Analysis Summary Report
Marshall Space Flight Center

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1. STS-99 Engineering Photographic Analysis Mission

The launch of space shuttle mission STS-99, the fourteenth flight of the Orbiter Endeavour occurred February 11, 2000, at approximately 11:43AM Central Standard Time from launch complex 39A, Kennedy Space Center (KSC), Florida. Launch time reported as 042:17:43:39.997 Universal Coordinated Time (UTC) by the MSFC Flight Evaluation Team.

Photographic and video coverage has been evaluated to determine proper operation of the flight hardware. Video and high-speed film cameras providing this coverage are located on the fixed service structure (FSS), mobile launch platform (MLP), perimeter sites, Eastern Test Range tracking sites and onboard the vehicle. Additional information concerning photographic analysis of this and previous space shuttle missions is available on the MSFC Engineering Photographic Analysis website at URL:

http://photo4.msfc.nasa.gov/STS/sts.html.

2. Photographic Coverage

Sixty-eight engineering photographic products consisting of launch video, ground-based engineering films and video and onboard film were received and reviewed at MSFC. Good coverage of the launch was obtained. No film from camera E7 was received. Camera coverage received at MSFC for STS-99 is illustrated in the following table.

Table 1 . Camera Coverage

Camera Location	16mm	35mm	Video
MLP	19	0	4
FSS	5	0	3
Perimeter	0	7	6
Tracking	0	10	10
Onboard	2	2	0
Totals	26	19	23

The Photographic Acquisition Document Data (PADD) and information regarding individual camera status and assessments may be found on the website.

3. Individual Camera Assessments:

Notable assessments for individual cameras are listed below. The complete assessments for all individual cameras for flight STS-99 may be found on the website.

3.1 Video Camera Assessments

TV12 - SRB separation 042:17:45:45.5. Faint streak from SSME#1 was noted at 042:17:44:06.002 UTC. A very bright, apparently debris induced streak in SSME #1 occurred at 042:17:44:06.369 UTC. What appears to be debris induced streaks in both SSME #1 and #2 occurred at 042:17:44:23.853 UTC.

TV13 - Linear optical distortions noted. SRB separation at 042:17:45:45.47 UTC.

TV7A - Plume brightening in SSME #1 occurred at 042:17:43:49.743, 042:17:43:49.943 and 042:17:43:49.977 UTC.

TV21A - Flight path adjustments observed at approximately 1 minute MET(?).

OTV041 - Camera had very soft focus. Tracks vehicle for very short time.

OTV051 - Mach diamonds form in 3-2-1 order.

OTV070 - Five faint color changes in SSME #1 noted at the following times: 042:17:43:37.938, 042:17:43:38.272, 042:17:43:39.239, 042:17:43:39.740, 042:17:43:40.204 UTC.

OTV071 - Bright spot (flash) appears under the MLP as SRB ignition occurs at 042:17:43:40.221 UTC. Sunlight flash noted on GUCP retraction arm as it falls away from vehicle.

ET204 - SRB separation: 042:17:45:45.475 UTC.

ET207 - SRB separation: 042:17:45:45.469 UTC. Camera experienced soft focus.

ET208 - SRB separation: 042:17:45:45.491 UTC.

ET212 - SRB separation: 042:17:45:45.494 UTC. Streaks noted in SSME plume.

3.2 Film Camera Assessments

E2 - Faint engine streaks observed in SSME#1 plume at times: 42:17:43:37.634, 42:17:43:37.687, 42:17:43:37.707, 42:17:43:37.944, 42:17:43:38.365, 42:17:43:38.503, 42:17:43:39.055, 42:17:43:39.090 UTC.

E3 - Faint engine streaks noted in SSME#1 plume at times: 42:17:43:37.687, 42:17:43:37.855, 42:17:43:37.945(whole plume changes color), 42:17:43:38.368, 42:17:43:38.504, 42:17:43:38.639, 42:17:43:39.055, 42:17:43:39.090, 42:17:43:39.243, 42:17:43:40.198 (wide streak), and 42:17:43:40.626 UTC.

E6 - Frost noted on orbiter-ET attach hardware.

E7 - Spacing between thermal curtain sections similar to that observed from camera E-13 and E-14.

E8 - PIC firing time 42:17:43:40.006 UTC.

E9 - PIC firing time 42:17:43:40.006 UTC. Holddown post shoe shim material falls into flame trench at lift-off.

E12 - PIC firing time 42:17:43:40.006 UTC.

E13 - PIC firing time 042:17:43:40.005 UTC. Seam between two sections of thermal curtain is open.

E14 - Stitching connecting two adjacent SRB thermal blankets near Holddown post M-8 appears loose.

E18 - Vehicle backlit by sun and little detail was discernable of the LH2 T0-Umbilical separation.

E19 - Faint streaks in SSME#1 plume at times: 42:17:43:37.686, 42:17:43:37.708, 42:17:43:37.854, 42:17:43:37.944, 42:17:43:37.983, 42:17:43:38.363, 42:17:43:38.504, 42:17:43:38.638, 42:17:43:39.053 (broad color change in plume), 42:17:43:39.090, 42:17:43:39.244, 42:17:43:39.735, 42:17:43:40.201, and 42:17:43:40.550 UTC. A faint streak was observed in SSME#3 plume at 42:17:43:37.391 UTC.

E20 - Faint engine streaks in SSME#1 plume similar to that of Camera E19. Engine streak observed in SSME#2 plume.

E34 - Thin flat dark object of unknown origin, falls through field of view. No contact with vehicle.

E36 - Debris noted in Camera E-34 was not observed here, indicating the debris was close to Camera E-34 and not close to the vehicle.

E40 - Streak observed in SSME#1 plume at 42:17:43:44.539 UTC. Timing block appears to come loose inside camera.

E52 - Engine streaks observed in SSME #1 plume at 042:17:43:38.511 UTC and 042:17:43:39.245 UTC. Camera loses track of vehicle earlier than planned.

E54 - Camera loses track of vehicle earlier than expected.

E57 - Streak observed in SSME#1 plume at 042:17:43:45.845 UTC.

E63 - Flash observed at 042:17:43:40.214 UTC under MLP after SRB ignition.

E204 - Short run; vehicle never comes into focus.

E205 - Debris-induced streak in SSME plume. SRB separation not visible due to cloud cover.

E207 - Linear optical distortions noted. Detailed engineering evaluation was not possible due to light exposure and soft focus.

E213 - Debris particle observed forward of SSMEs at 042:17:43:53.406 UTC. This particle caused streak in SSME #1 observed at 042:17:43:53.426 UTC.

E220 - Debris-induced streak in SSME plume.

E222 - Debris noted on +Z side of vehicle at 042:17:44:06.681 UTC. Several streaks were observed in SSME plumes. A probable engine streak was observed at 042:17:44:06.014 UTC. Three debris induced streaks were timed at 042:17:44:06.379 UTC and 042:17:44:23.862 UTC.

E223 - Debris-induced streaks in SSME plume. Simultaneous debris induced streaks in SSME#1 and SSME#3 plumes.
E224 - Debris-induced streaks in SSME plume.
UMB2 - Two areas of concentrated popcorning on the aft dome near the LH2 disconnect were observed.
UMB3 - Five large divots were noted near or on the LH2 tank-to-intertank closeout flange. One large divot beneath the legs of the forward ET/Orbiter attach bipod and two smaller divots further along the flange in the -Y direction. Two more large divots located in the +Y direction with one near the LO2 feedline and the other near the ET +Y thrust panel. Typical TPS loss on the LO2 Feedline and one large thin surface TPS loss on the aft right tripod thrust strut.

4. T-Zero Times

T-Zero times are determined from MLP cameras that view the SRB holddown posts numbers M-1, M-2, M-5, and M-6. These cameras record the explosive bolt combustion products.

Table 2. T-Zero Times

Holddown Post	Camera Position	Time (UTC)
M-1	E9	42:17:43:40.006
M-2	E8	42:17:43:40.006
M-5	E12	42:17:43:40.006
M-6	E13	42:17:43:40.005

5. SRB Separation Timing

SRB separation time, as recorded by observations of the BSM combustion products from long-range film camera E-207, occurred at approximately 42:17:45:45.511 UTC.

6. Observations:

6.1 Film Camera E222 (A)

A brightening of the entire SSME Plume was observed at 042:17:44:06:002 UTC by Film Camera E222. Multiple Mach diamonds are more visible during the brightening of the plume.

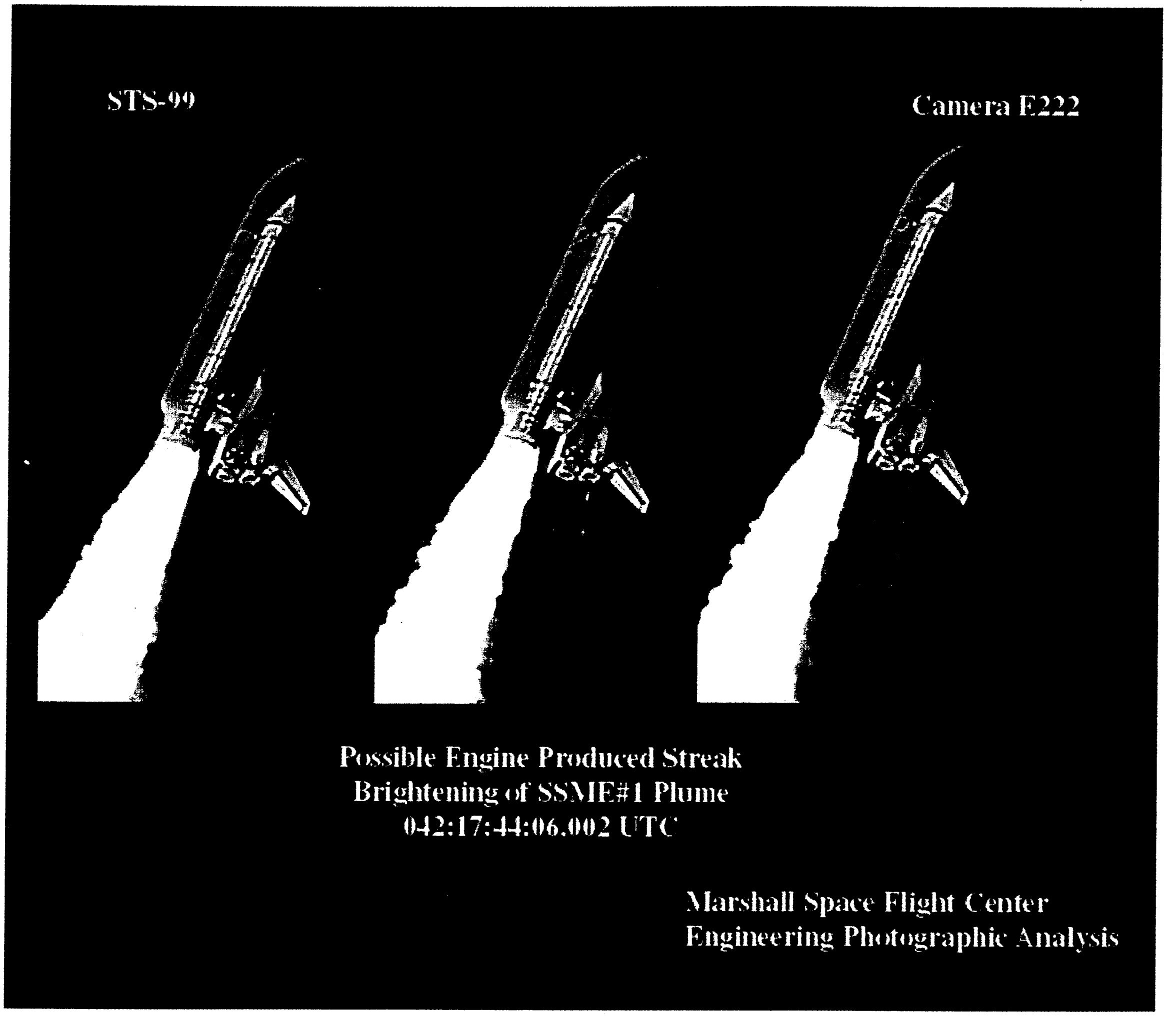

Figure 1. Brightening of SSME Plumes

6.2 Film Camera E222 (B)

A bright debris induced streak during vehicle ascent was observed by Film Camera E222 at time 042:17:44:06.379 UTC.

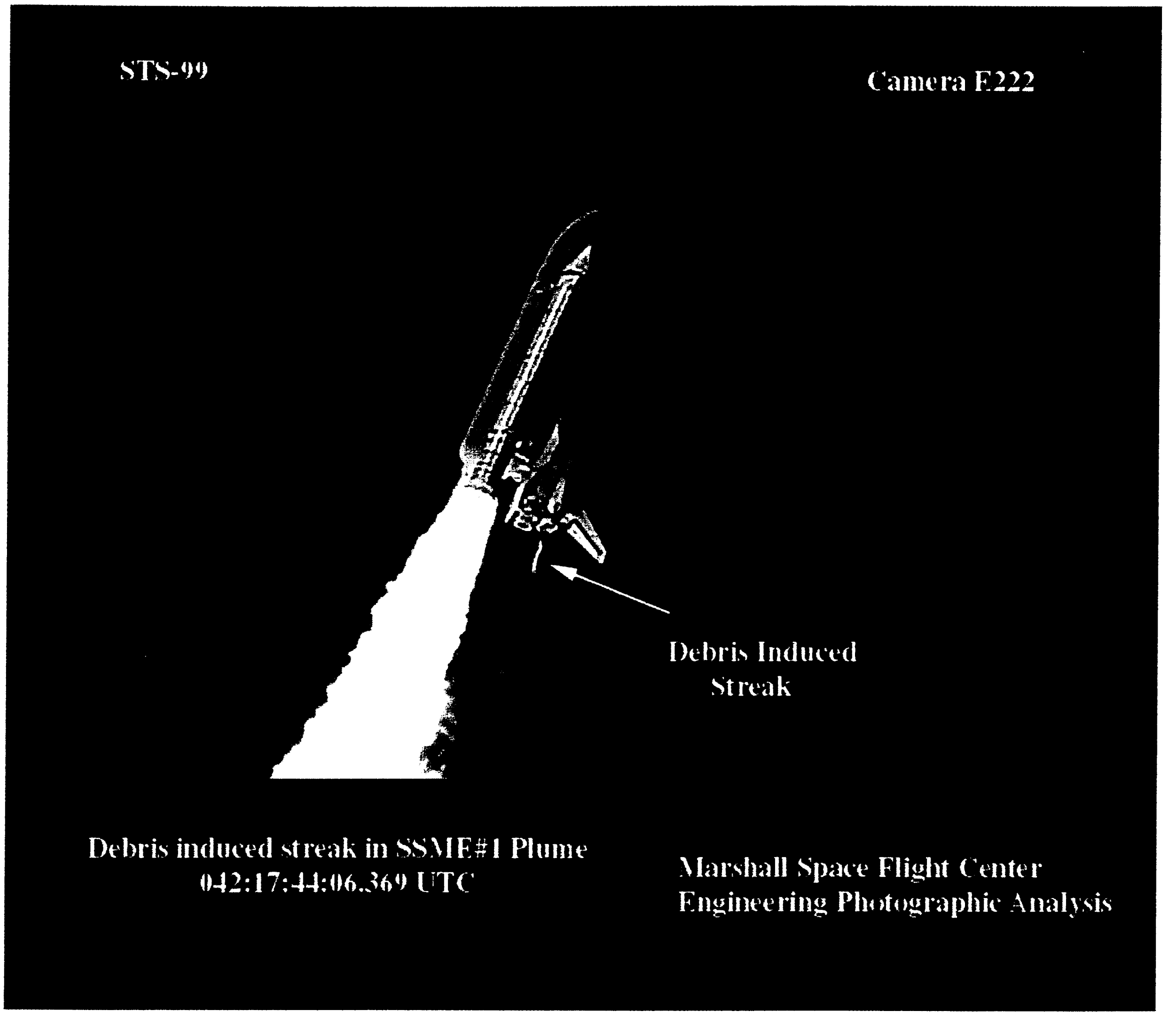

Figure 2. Debris Induced Streak in SSME Plume

6.3 Video Camera TV-12(A)

Another view of the debris induced streak in SSME#1 plume during ascent captured by Film Camera 222. Film Camera E222 operates at 100 fps while TV-12 operates at normal video capture speeds, 30 fps. Timing from the film cameras is in general more accurate than timing from video cameras and therefore film and video yield differing times for events.

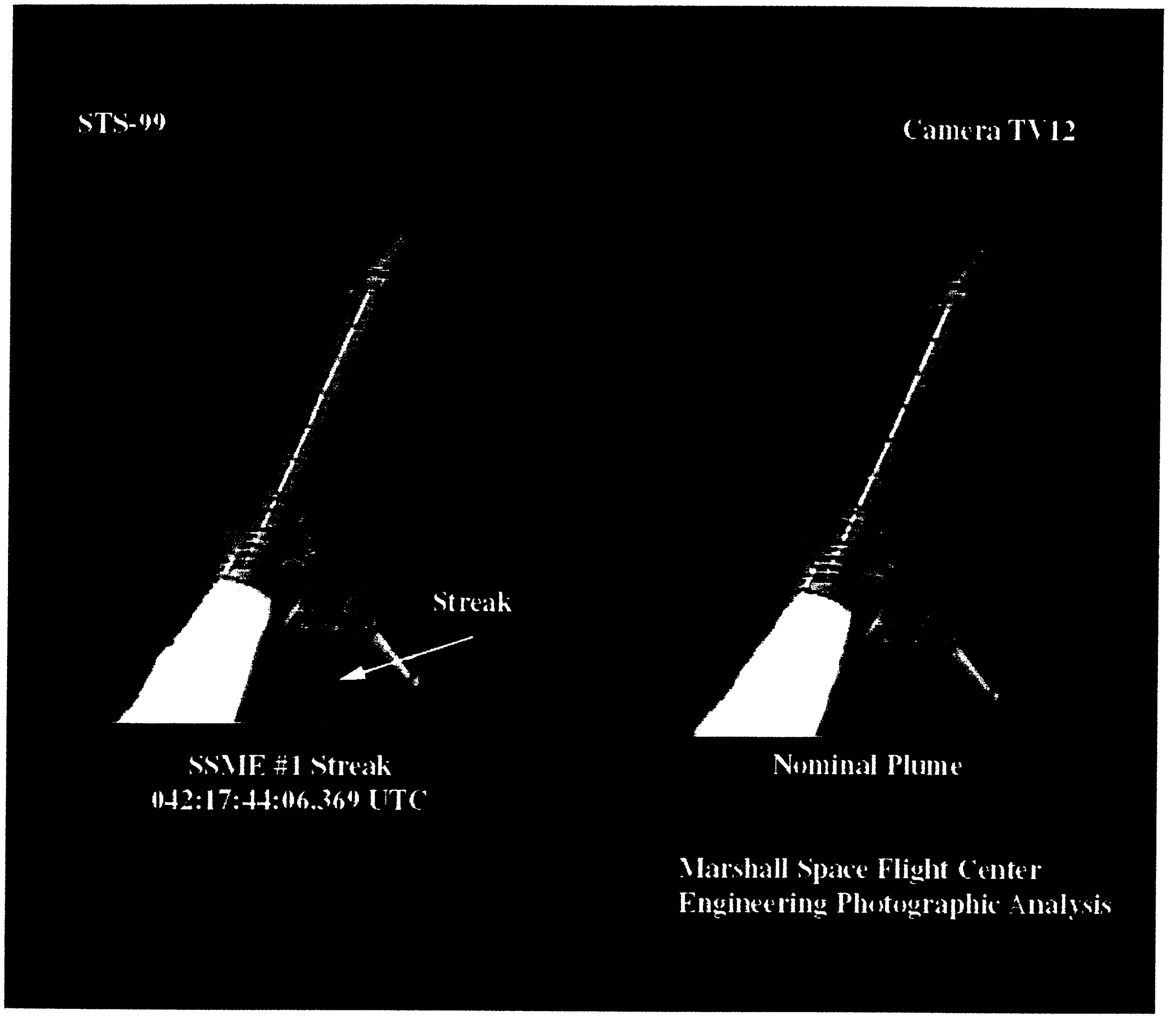

Figure 3. Debris Induced Streak Observed by Video Camera TV-12

6.4 Film Camera E223

A sequence of frames from the 35mm Film Camera E223 showing two streaks originating almost simultaneously in the SSME plumes. This event was timed at 042:17:44:23.862 UTC by Film Camera E222.

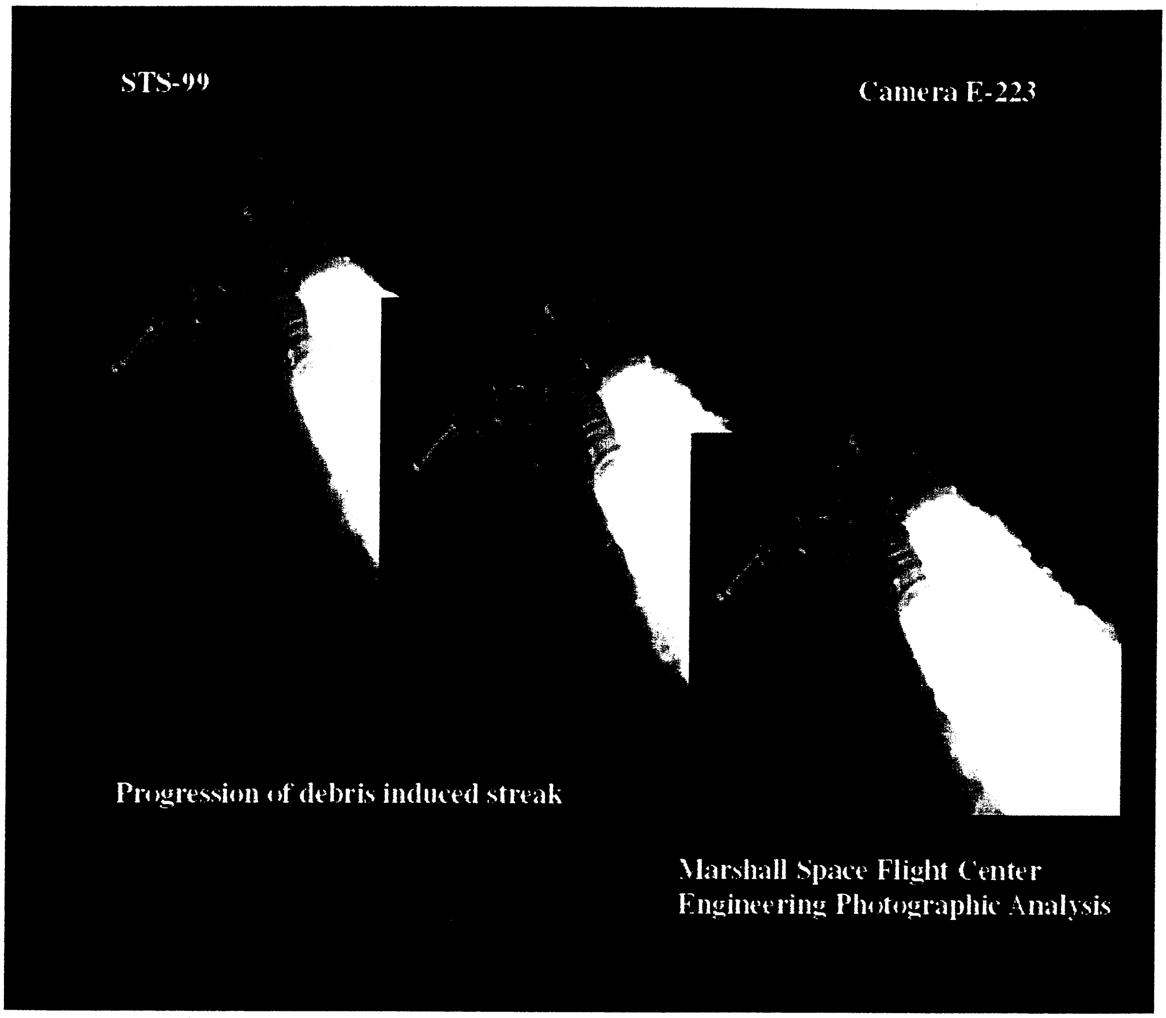

Figure 4. Streaks in SSME Plumes

6.5 Video Camera TV-12(B)

Another view of the simultaneous debris induced streaks in SSME plumes during ascent is shown in Figure 4. This event occurred at approximately 042:17:44:23.853 UTC according to TV-12 timing.

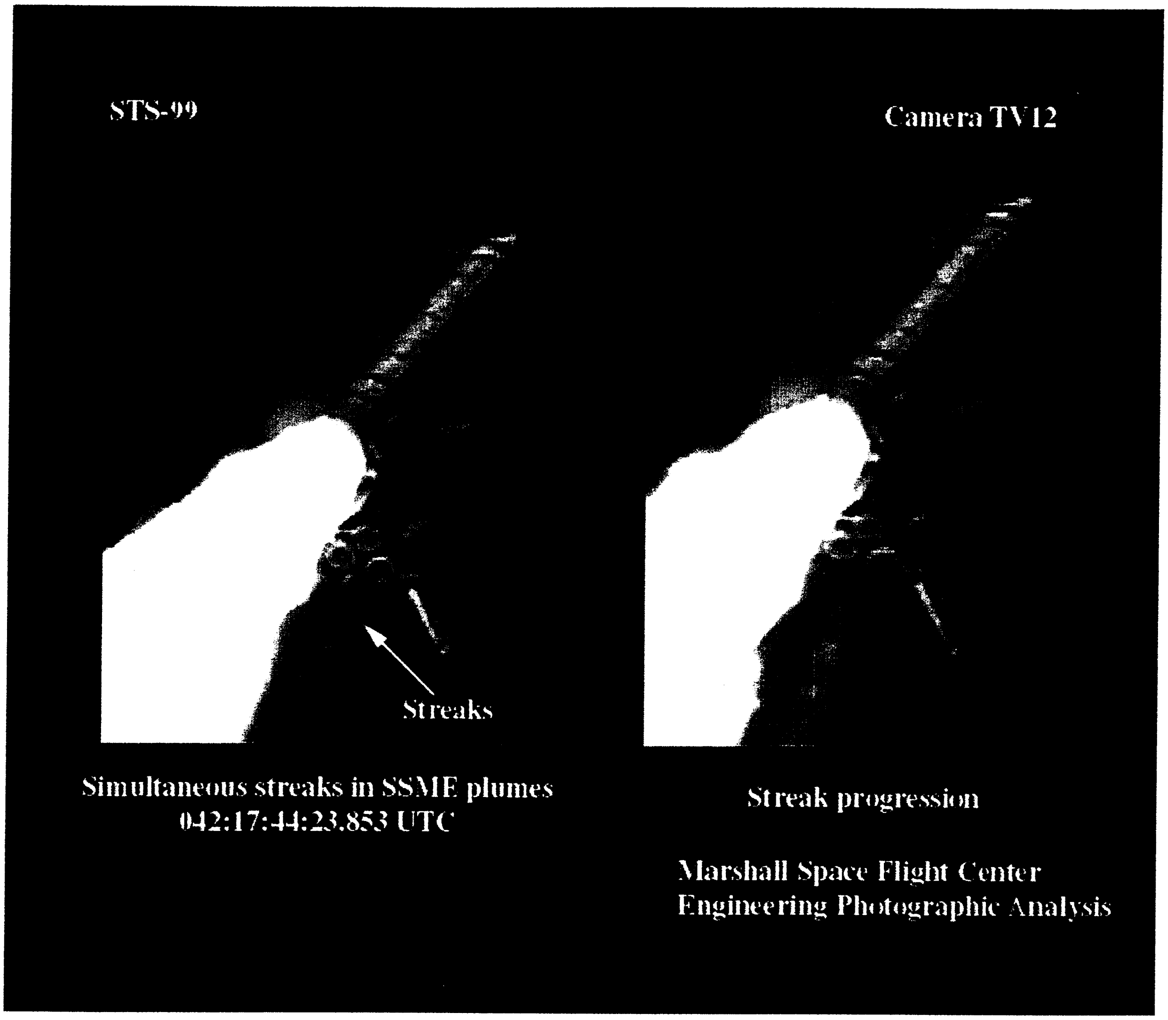

Figure 5. Simultaneous Streaks Observed by Video Camera TV-12

6.6 Video Camera TV071

A brief flash was observed under the Mobile Launch Platform (MLP) just after SRB ignition, the event shown in Figure 6 was timed at 042:17:43:40.220 UTC.

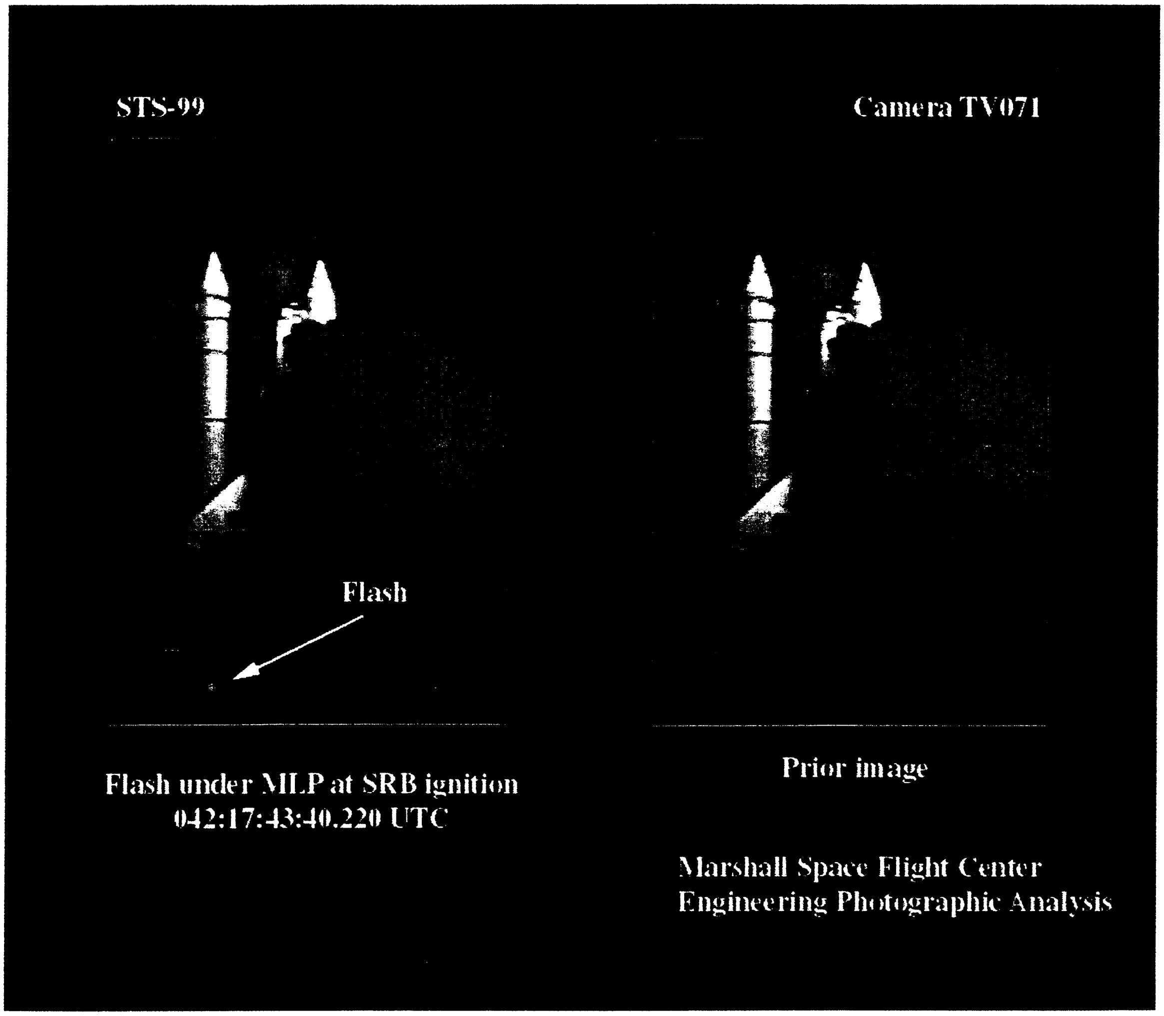

Figure 6 . Flash under MLP at SRB Ignition

6.7 Film Cameras E7/E13/E14

The following views from Film Cameras E7, E13, and E14 show separation of adjacent SRB thermal blankets. Film Camera E13 views SRB Holddown Post M-6. The thermal blanket was separated and stitching could be seen protruding through the separated blankets. Film Camera E7 views SRB Holddown Post M-4 and Film Camera E14 views SRB Holddown Post M-8. The thermal blanket was separated in these views, but no thermal insulation was visible.

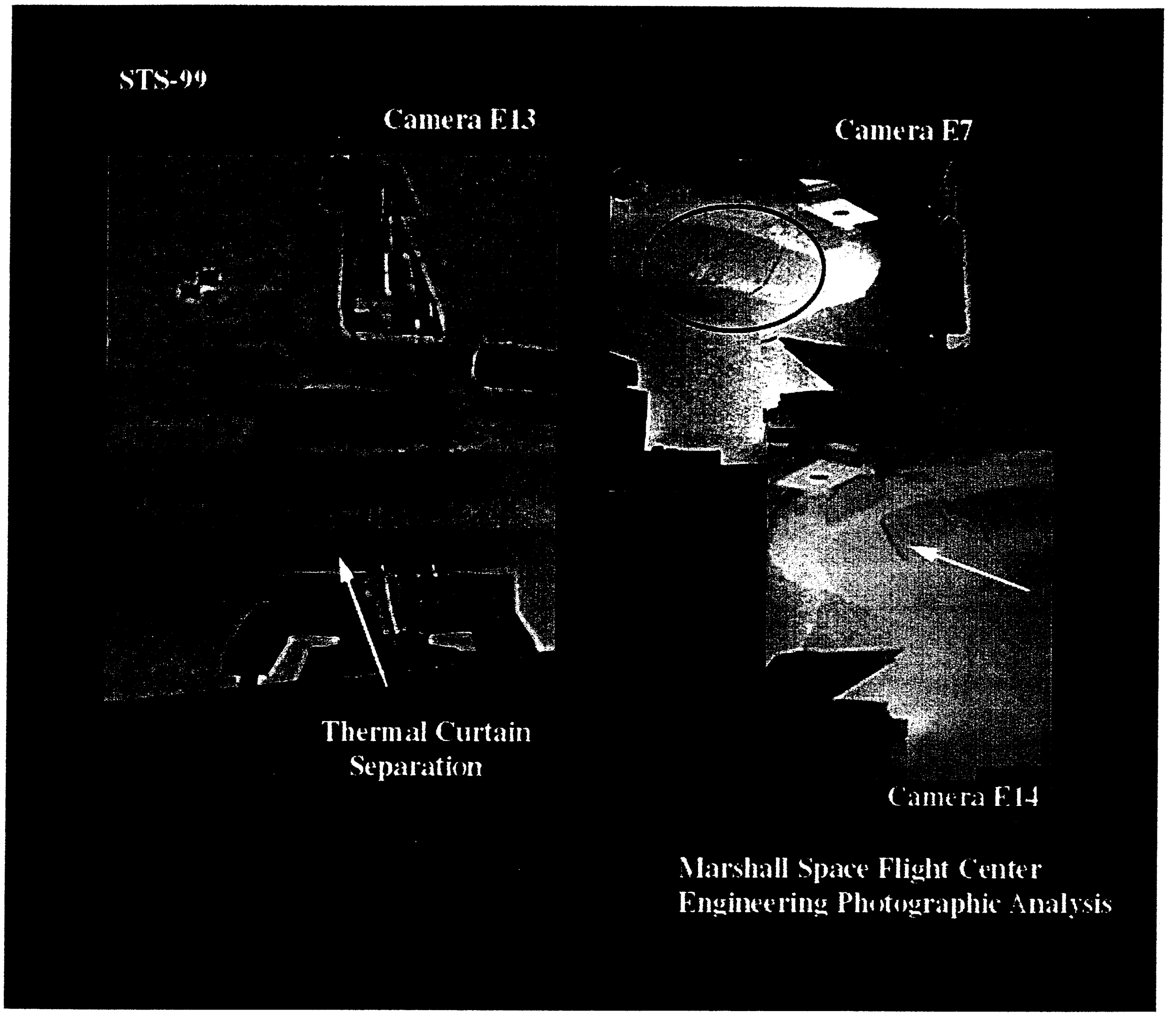

Figure 7. Separated Thermal Blankets

6.8 On Board Hand Held Camera

Views of the External Tank (ET) after separation from vehicle, showing the condition of the Thermal Protective Surface (TPS) and ET venting. No obvious or large scale TPS divoting is observed, scarring of TPS from BSM motor firing appears normal. Typical venting from the GUCP was easily observed due to the lighting conditions at the time of ET separation.

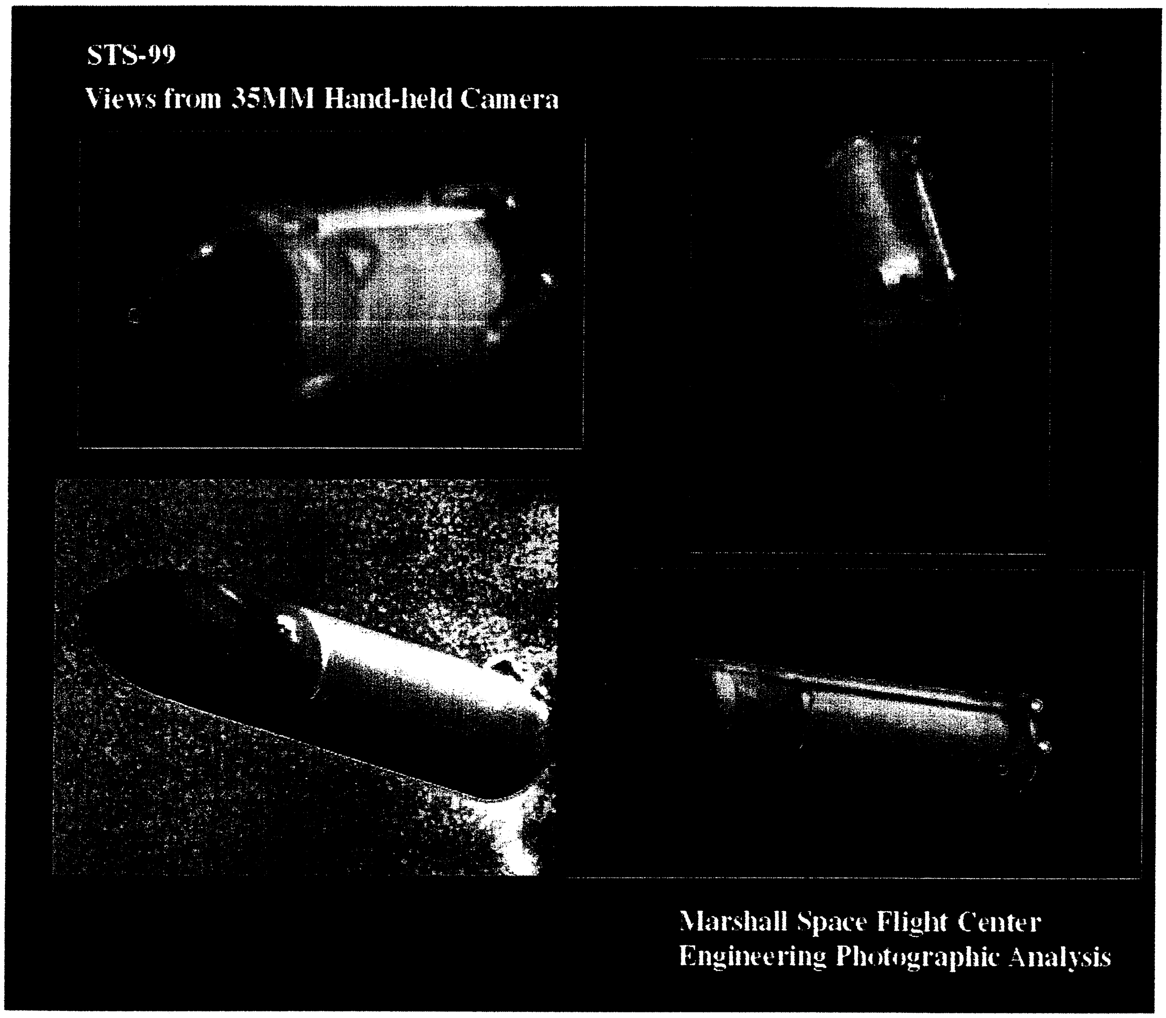

Figure 8. View of the ET from On-board 35mm Hand-held Camera

6.9 35mm Umbilical Well Camera (A)

Five large divots were observed on the +Z side of the ET near the LH2 tank-to-intertank closeout flange. One divot at the +Y thrust panel to stringer interface slightly forward of the LH2 tank-to-intertank flange, another on the +Y side of the LH2 tank cable tray, another under the forward ET/ORB attachment bipod, and two on the –Y side outboard from the bipod housing.

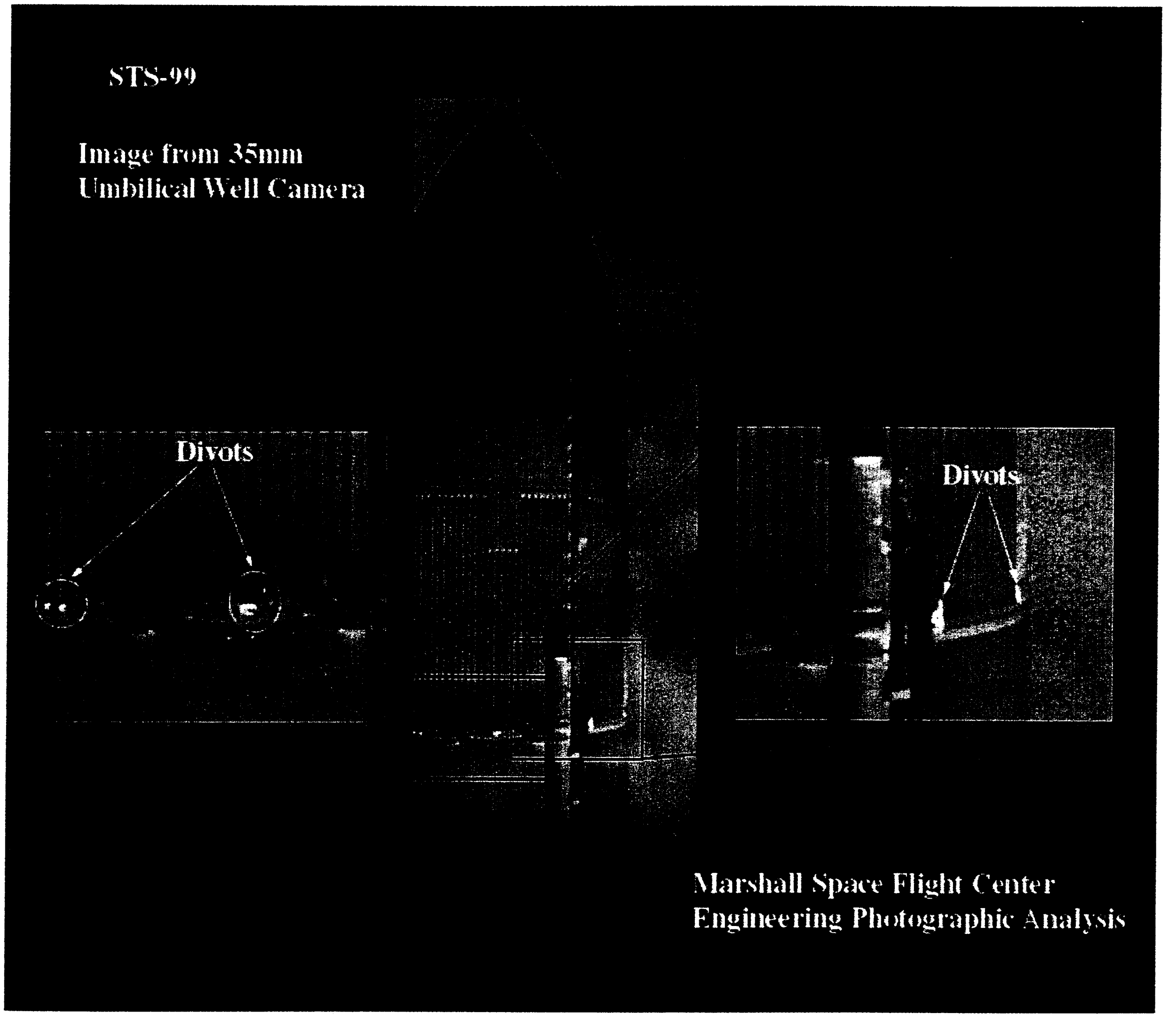

Figure 9. TPS Divoting on the +Z Forward Section of ET

6.10 35mm Umbilical Well Camera (B)

Areas of TPS loss on the aft of the ET and frost on the LO2 feedline bellows are shown. Typical popcorning was observed on the aft dome, aft thrust struts, and the LO2 feedline. Large area of TPS surface material on the aft right thrust strut is gone.

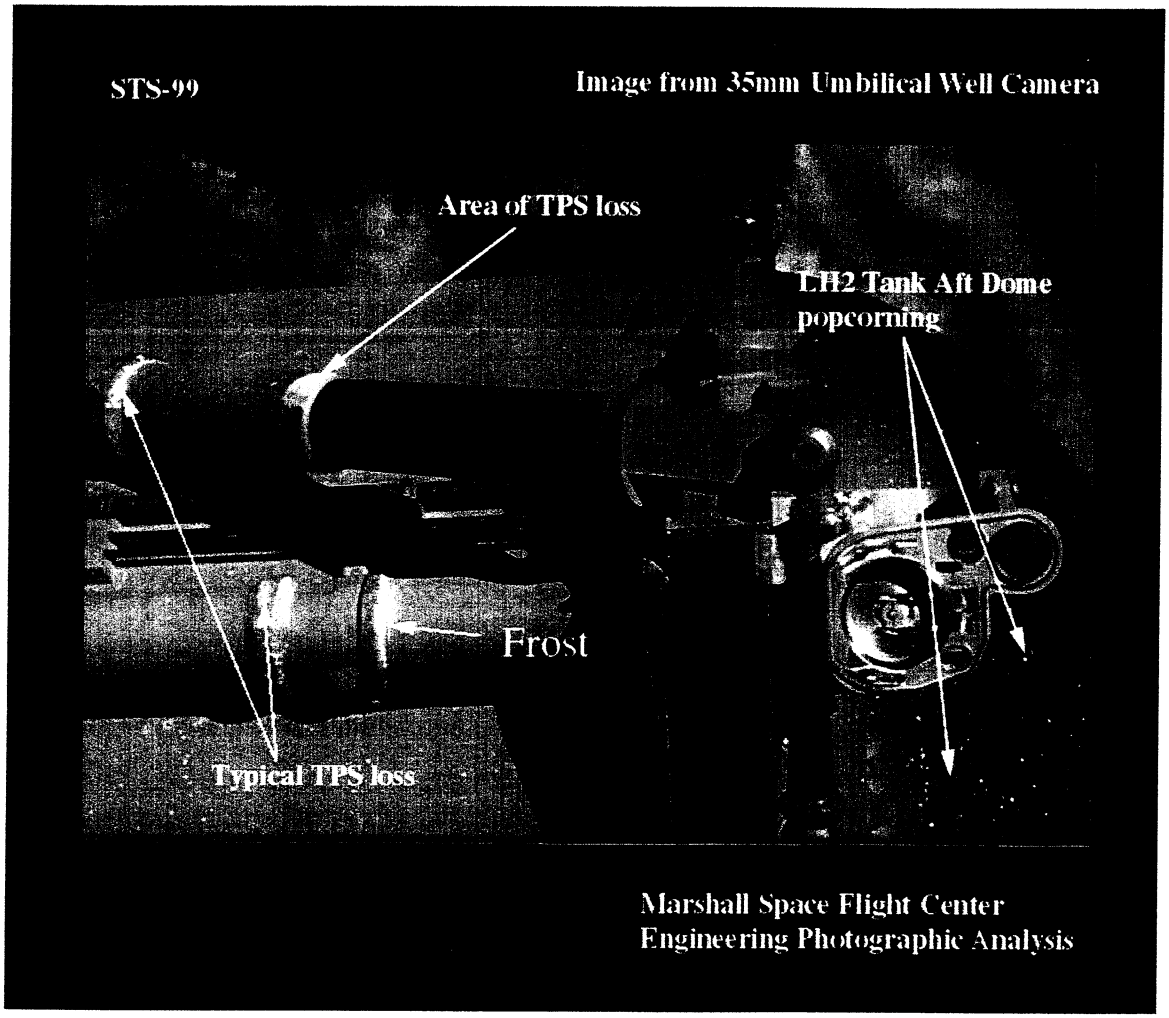

Figure 10. Aft Dome TPS Loss

6.11 16mm Umbilical Well Camera

Popcorning was noted on the aft dome. Typical ice/frost formations were observed near aft ET/Orbiter diagonal cross strut attach structure.

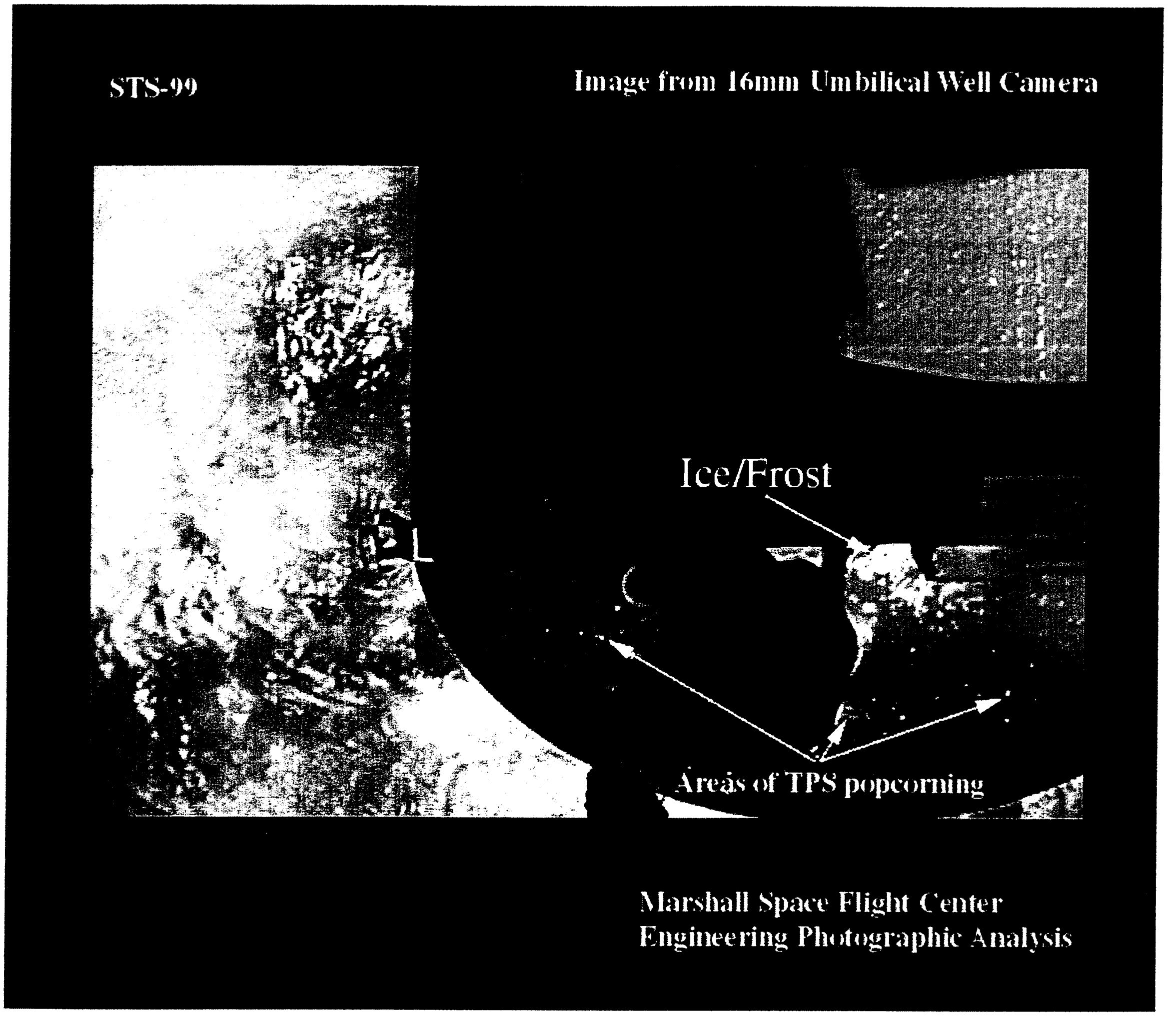

Figure 11. Aft Dome Popcorning

7. SSME Streak Time-Line

The following table is a timeline of SSME plume streaking starting from the first streak observed after attaining mainstage to the last streak observed before lift-off. The timeline is a composite of the streaks observed by several cameras, Film Cameras E2, E3, and E-19.

The graph following illustrates the timing engine produced streaks in the SSME#1 plume as observed by Camera E-19 from several missions. Although, nearly all streaks observed were faint, the number of such streaks observed in the past two flights is showing an increase.

Table 3. Streak Timeline

Time	Engine
42:17:43:37.634	1
42:17:43:37.686	1
42:17:43:37.687	1
42:17:43:37.707	1
42:17:43:37.708	1
42:17:43:37.854	1
42:17:43:37.854	1
42:17:43:37.944	1
42:17:43:37.945	1
42:17:43:37.983	1
42:17:43:38.363	1
42:17:43:38.365	1
42:17:43:38.368	1
42:17:43:38.503	1
42:17:43:38.504	1
42:17:43:38.638	1
42:17:43:38.639	1
42:17:43:39.053	1
42:17:43:39.055	1
42:17:43:39.090	1
42:17:43:39.243	1
42:17:43:39.244	1
42:17:43:39.735	1
42:17:43:40.198	1
42:17:43:40.201	1
42:17:43:37.391	3
42:17:43:40.550	1
42:17:43:40.626	1
42:17:43:44.539	1

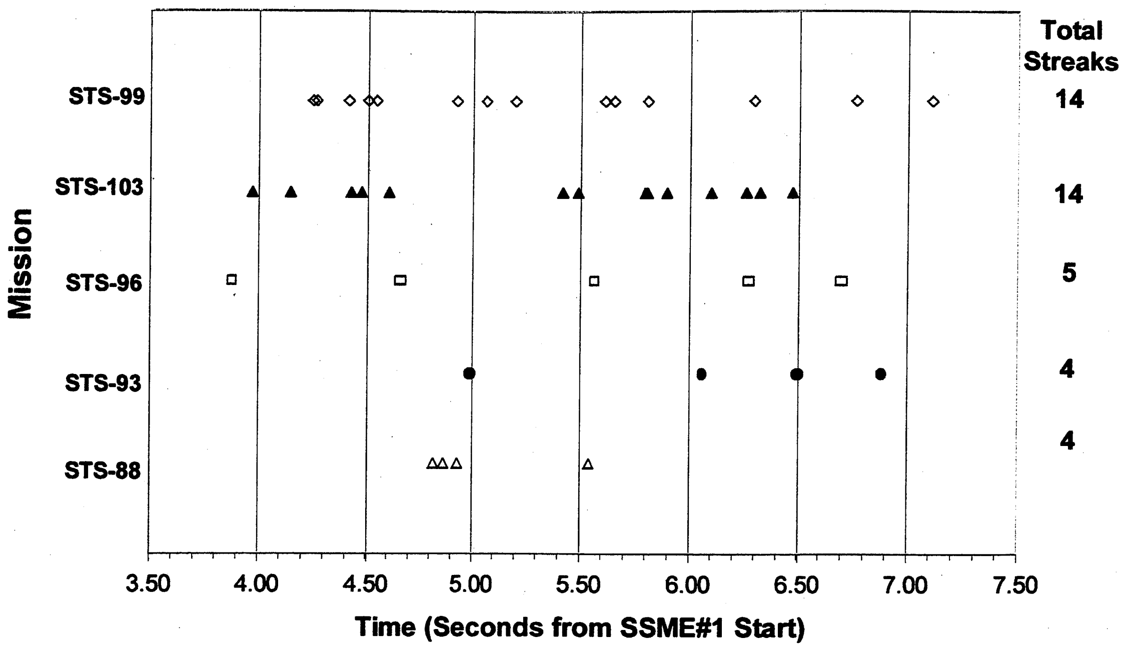

Figure 12. Streak Comparison Timeline for Camera E-19

For further information concerning this report contact Tom Rieckhoff at 256-544-7677 or Michael O'Farrell at 256-544-2620.

Tom Rieckhoff/TD53

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13. ABSTRACT *(Maximum 200 words)*

A debris/ice/thermal protection system assessment and integrated photographic analysis was conducted for Shuttle mission STS-99. Debris inspections of the flight elements and launch pad were performed before and after launch. Icing conditions on the External Tank were assessed by the use of computer programs and infrared scanned data during cryogenic loading of the vehicle, followed by on-pad visual inspection. High speed photography of the launch was analyzed to identify ice/debris sources and evaluate potential vehicle damage and/or in-flight anomalies. This report documents the debris/ice/thermal protection system conditions and integrated photographic analysis of Space Shuttle mission STS-99 and the resulting effect on the Space Shuttle Program.

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